DESIGN AND IMPLEMENTATION OF AN INTEGRATED MRP-GT SYSTEM FOR CIMS ENVIRONMENT

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CERTIFICATE

Certified that the work on "Design and Implementation of an Integrated MRP-GT System For CIMS Environment", by Mr. V. Ratna Kumar, has been carried out under my supervision and it has not been submitted elsewhere for the award of a degree.

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ABSTRACT

In the present work, an attempt is made to integrate the two important manufacturing philosophies - Material Requirements Planning (MRP) and Group Technology (GT) - relevant to multi-product, medium batch-size production environment.

The MRP system explodes the end item demands into item requirements using the product structure. Master Production Schedule (MPS), which is a specification of end item requirements, is examined for the feasibility of capacity for executing the MRP generated requirements on the shopfloor. This is achieved by iteratively carrying out Resource Requirements Planning (RRP), Rough Cut Capacity Planning (RCCP), Material Requirements Planning (MRP), and Capacity Requirements Planning (CRP).

An expert GT system is adopted to form part families and machine cells, using which a feasible MPS is developed by RRP, RCCP, MRP and CRP modules. The present implementation allows the generation of feasible MPS with and without GT to highlight the advantages of GT concepts at every stage of development of MPS. The MRP generated item requirements are scheduled for production using a group scheduling heuristic procedure, which minimizes the average tardiness criterion.

The integrated information system has been developed in TURBO PASCAL version 4.0 and implemented on a PC-XT/AT.

CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The development of Master Production Schedule Planning (MPSP) in a production system calls for decisions at various stages in a hierachial structure viz. forecasting (demand management), aggregate production planning, resource requirements planning (RRP), rough cut capacity planning (RCCP), material requirements planning (MRP), capacity requirements planning (CRP), and shopfloor scheduling for manufactured items and vendor follow-up for purchased items. There is a vast literature available on the development of MPSP in a conventional production system. The objective of this thesis work is to systematically design and develop a capacity constrained MPSP in a cellular production system. The approach includes integration of group technology (GT) technique with MRP. Though there are some investigations made into integrating MRP and GT, there is a clear vacuum existing in the area of developing MPSP in a cellular manufacturing system. The present work attempts to fill this vacuum and illustrates the advantages of using GT at various stages in the development of MPSP. A somewhat sophisticated method based on an expert system is employed to form groups comprising of part families and machine cells. The characteristic advantages of these groups are used in developing feasible MPSP and the corresponding material

requirements. The material requirements are group scheduled to minimize total tardiness criterion using a heuristic approach.

The following sections present an overview of some of the relevent key concepts.

1.2 BASIC CONCEPTS

1.2.1 Master Production Schedule Planning

The various hierachial decisions involved in the development of a feasible MPSP are depicted in Fig 1.1. It starts from the forecasting of demand. The demand figures are used to establish aggregate production planning, which must be translated into a master production schedule (MPS). The MPS specifies how many units of each product are to be delivered and when. In turn, this MPS must be finally converted into purchase orders for raw materials, orders for components from outside vendors, and production schedules for parts made in the shop by material requirements planning (MRP) system. Conventional MRP is highly capacity insensitive in that it assumes that MPS is feasible to execute on the shopfloor and generates the material requirements. But there must be a correspondence between the capacity required to execute a material plan and that is available to execute the system. If the correspondence does not exist, the plan will either be impossible to execute or poorly executed. To obliviate this, the MPS must be made feasible, before evaluating material requirements. This is achieved through resource requirements planning (RRP), rough cut capacity planning (RCCP), material requirements planning (MRP), and

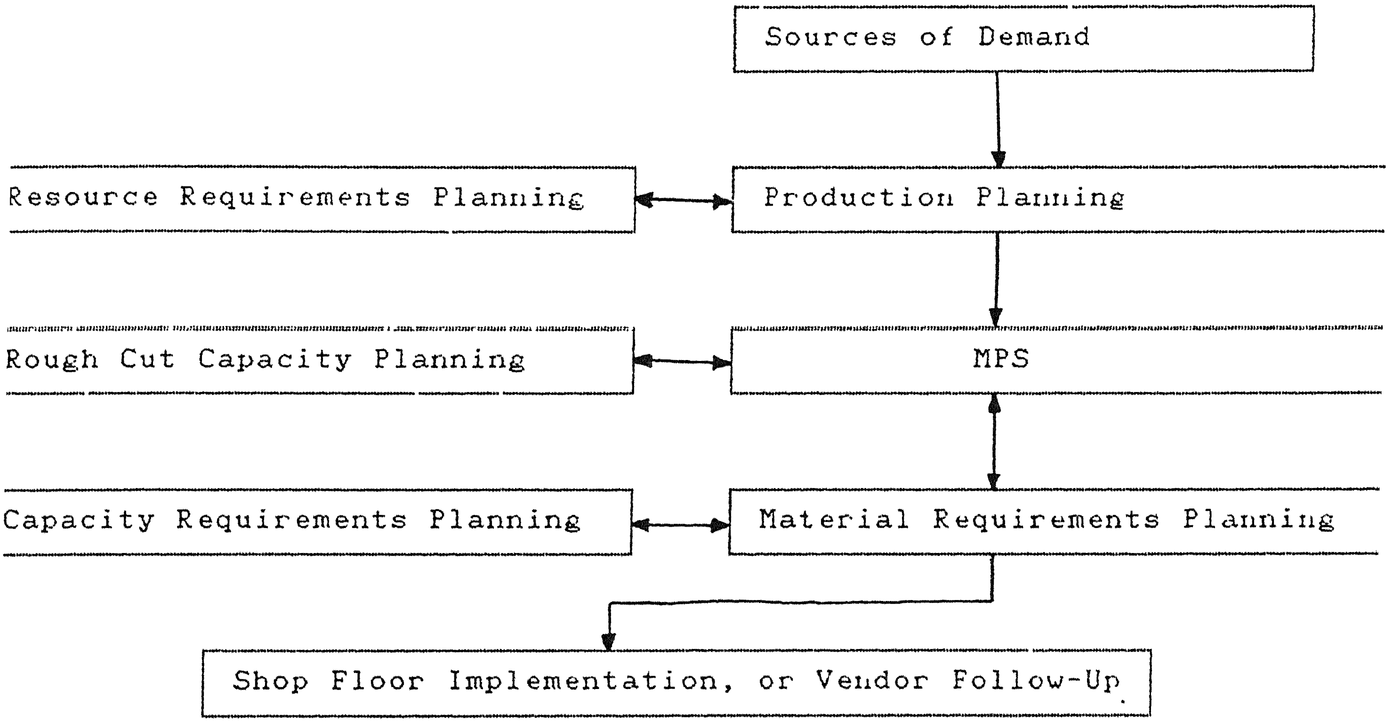


Fig 1.1 : Hierachial Decisions in MPS Development

capacity requirements planning (CRP). The RRP is a long term resource planning and is generally carried out for average demand over a production planning horizon. It deals with aggregate product families. The RCCP deals with individual items instead of product families. The period size is relatively shorter to that of RRP and is generally carried out for each period in the planning horizon. To reduce the computation, critical work centres which may cause bottleneck problems in order to satisfy the demand are identified at product family level. The output of RCCP, which is termed as 'Authorized MPS' will be fed to MRP module to generate item level requirements in each bucket. A detailed capacity planning is possible with CRP. The input to CRP consists of bucket material requirements to investigate capacity availability at each work center in each bucket. The concepts of RRP, RCCP, MRP, and CRP are covered in detail in Chapter III.

1.2.2 Material Requirements Planning

Material requirements planning (MRP), known as time-phased requirements planning, is a computer based production planning and control system that is designed to work well for discrete production (Orlicky [1], Tersine [2]). Discrete products such as automobile and machine tools are made up of a number of components which often assume the form of a hierachial structure. Hence, whether the discrete products are efficiently produced according to their production schedule or not depends highly on the establishment of an effective production and control system that guarantees that components composing the

products are available in necessary quantities when needed. The conventional reorder point control systems, mainly used for controlling inventories of independent items, is not appropriate for the components that are dependent on items directly related to the demand for higher level items in the product structure. The demands of the items are not to be forecasted but are calculated based on a master production schedule (schedule of end items). MRP calculates the demand of the components and time phases the lot sized requirements. Three major inputs into to an MRP system are:

(a) Master Production Schedule : This outlines which products (i.e.end items), how many are to be produced and when they are to be delivered to customers.

(b) Bill of Materials : This file defines the product structure of products.

(c) Inventory Status Records : This file contains various aspects of information on inventory items - item master data such as item identifications, lead times, order quantities, lot sizing etc. Also included are inventory status data such as on-hand inventory status, scheduled receipts and others.

Based on these three inputs, MRP computes how many of each component in all levels in the product structure are required and when they are needed by exploding the requirements of products into successively lower levels. The requirements are converted into planned order releases by offsetting the leadtime for each item.

1.2.3 Group Technology

There are myriad of problems in batch-type manufacturing because of its characteristics, such as variety of products with small lot sizes, variety of production processes and complexity of productive capacity, uncertainty of external conditions, difficulty of production planning and scheduling and dynamic situations of implementation and control of production (Ham [3]). Several systematic approaches have been developed to overcome difficulties involved in batch-type manufacturing in the job shop. One of these approaches that received a great deal of recognition in recent years is Group Technology (GT), which is particularly applicable in the area of multi-product, batch-type manufacturing (Gallagher [4], Arn [5], Burbidge, J.L. [6]).

Group technology is the realization that many problems are similar and that by grouping similar problems, a single solution can be found to a set of problems, thus saving time and effort. The basis of group technology is the recognition that similarities occur in the design and manufacture of discrete parts. The underlying basis of group technology is relatively simple: identify and group together similar parts to take advantage of their similarities in design and/or manufacturing.

There are several definitions of group technology which are similar to each other. Summing up these definitions, group technology can be defined as "A manufacturing philosophy for the higher manufacturing productivity of the batch-type manufacturing system in which similar parts are identified and grouped

together based on similarities of geometrical shape and/or operation processes to take advantage of their similarities in all the areas of integrated manufacturing systems, under both conventional manufacturing environments and computer integrated manufacturing (CIM) environments ". In batch-type manufacturing, it is possible to increase productivity and to reduce manufacturing costs through the effective application of group technology concept. For example, grouping similar parts into part families and/or forming machine groups or cells which process the designated part families will result in economies of scale. In general, the implementation of GT will yield benefits in areas such as product design, tooling and setup, production and inventory control, process planning, material handling and employee satisfaction (Ham [3]).

There are many direct and indirect benefits that result from implementing GT in manufacturing (a) Mass production effect for higher productivity, (b) Possibility of flow shop production, (c) Product design benefits by design rationalization through an effective design data retrieval system, (d) Reduction of setup time through group setup and group tooling, (e) Less work-in-process inventory and work movement, (f) Better production scheduling, (g) Reduced process planning and possibility of leading to computer aided process planning, (h) Increased job satisfaction, (i) Increased reliability of labor and material estimation and costing accuracy, (j) Efficient utilization of machine tools including expensive, NC machines and machining

centers, (k) Better product quality, and (l) Overall cost reduction.

One of the basic requirements for implementation of group technology is the grouping of similar parts into part families. The various methods available for forming groups can be classified into (a) visual inspection, (b) parts classification and coding system, and (c) clustering analysis or production flow analysis (Groover [7]).

The visual inspection method is the least sophisticated and least expensive method. It involves the classification of parts into families by looking at either the physical parts or photographs and arranging them into similar groups.

The second method, parts classification and coding system, involves an examination of the individual design and /or manufacturing attributes of each part. The attributes of the part are are uniquely identified by means of a code number.

The clustering analysis method is based on analysis of production route sheets of components and bringing together the components requiring similar machines.

The parts classification and coding system and clustering analysis methods are discussed in detail in APPENDIX A.

However none of the three methods mentioned above will take the practical constraints on the shopfloor into consideration while forming groups. It is indisputable that there will be many a constraints such as processing time available on each

machine, the maximum machine length in a machine cell, technological sequence requirements dictating some machines to be included in the same machine cell etc. The groups designed will be more realistic by considering these constraints. Recently an expert system modelled by Andrew Kusiak [8], which makes an effort to incorporate the shopfloor constraints in an attempt to solve the generalized formulation of the group technology problem.

It is of primary importance to develop a feasible MPS prior to inputting to MRP module in the development of MPSP as detailed in Sec. 1.2.1. So it is pragmatic to include capacity constraints on the shopfloor to arrive at part family and machine cell combinations. Hence, the present work incorporates the development of groups using expert based group technology concept enunciated by A. Kusiak. This is dealt in detail in Chapter II.

1.2.4 Group Scheduling

The concept of group scheduling has recently been introduced in the area of production scheduling, which is the allocation of available production resources over time to best satisfy some set of criteria. GT has received much attention in production circles for eliminating or reducing the gap between theory and practice in production scheduling.

Production scheduling is simplified with group technology. Grouping of parts into families reduces the complexity and size of the total scheduling problem. Grouping of machines into cells reduces the number of production centres that must be

scheduled. Even though machine groups/cells are not formed, production scheduling can be simplified by the use of part families. As already mentioned, under group technology, the job flow is expected to follow a flow shop pattern. Hence concepts of flow shop scheduling can be applied to production scheduling under group technology environments rather than that of job shop scheduling.

Production scheduling associated with the GT concept is referred to as 'group scheduling (GS)' by Ham [3]. Group scheduling may be defined as " two-phased production scheduling associated with the group technology concept in which group sequence and job sequence in each group are determined to best satisfy some set of criteria, subject to the given feasible conditions".

Group scheduling has some specific features that differ conventional production scheduling. These are (a) A two-phase sequencing problem,(b) Reduction of setup times,(c) Possibility of flow shop pattern,(d) Reduction of problem size,(e) Overall economic savings.

In the present work the planned order releases of manufactured items generated by material requirements planning must be production scheduled on the shopfloor. The due dates of the items will be established by the manufacturing lead times of the items employed in evaluating the planned order releases in materials calculation. Under due date constraints in scheduling problems, time-dependent penalties are assessed on

late jobs, but no benefits are derived from completing jobs early. Thus, the objective of meeting job due dates translates to minimize the average total tardiness. The problem of minimizing total tardiness, which is referred to as tardiness problem, is considerably difficult, even in single machine problem, because tardiness is not a linear function of job completion time. This means that to find optimal solutions to such problems it is usually necessary to rely on the concepts of combinatorial optimization. Because of the complexities of combinatorial methods, there is apt to be more attention paid to efficient but sub-optimal solution techniques which can be easily used in practice.

A heuristic algorithm developed by Cho Kyu Kab [9] is used to solve the problem of group scheduling i.e determining sequencing of groups and jobs in each group on multi-stages with the objective of minimizing tardiness. The algorithm is employed to schedule the planned order releases of material requirements planning.

1.3 SCOPE AND ORGANIZATION OF THE PRESENT WORK

The present work is an attempt to integrate MRP and GT by group scheduling algorithm. However a feasible MPS is as important as MRP itself for implementability of its results. Hence a feasible MPS is developed to work well in a cellular manufacturing environment. The various hierachial decisions involved in developing MPS are RRP, RCCP, MRP and CRP. The advantages of adopting GT technique at each stage is highlighted in the development of MPS. Finally, the planned order

releases of MRP are group scheduled minimizing total tardiness criterion.

The relevant basic concepts have been discussed in the present chapter. The expert based group technology method used to obtain groups are discussed in Chapter II. The Chapter III details the MPS development in a cellular manufacturing system in parallel to conventional production system. The concepts of RRP, RCCP, MRP and CRP are dealt in detail. The group scheduling algorithm used to production schedule groups and jobs minimizing the tardiness criterion is the concern of Chapter IV. The Chapter V brings out some important design and implementation issues of the system developed. A user's manual for the integrated system developed in TURBO PASCAL version 4.0 is presented in Chapter VI. Appendix A reviews various methods commonly used to classify items into part families. Appendix B presents a sample output of the integrated system developed.

CHAPTER II

EXPERT GROUP TECHNOLOGY

2.1 INTRODUCTION

The basic concepts of group technology including various methods available for group formation are discussed in Chapter I. The importance of including shop floor constraints such as available time on each machine, processing time required on each machine, maximum machine length permitted in a machine cell and technological requirements of some machines to be included in the same machine cell etc. is also mentioned in Chapter I. In this chapter, a knowledge-based system (KBGT) for solving such a generalized formulation of group technology problem is discussed. The formulation follows the concepts proposed by Andrew Kusiak [8]. Two basic components of knowledge based system (KBGT), namely the expert system and heuristic clustering algorithm, are discussed. Each partial solution generated by the clustering algorithm is evaluated by the expert system, which modifies search directions of the algorithm.

2.2 FORMULATION OF THE GROUP TECHNOLOGY PROBLEM

The grouping problem considers the matrix $[t_{ij}]$, where $t_{ij} \geq 0$ is the processing time of part j on machine i.

The grouping problem can loosely be formulated as follows.

Group machines into cells; for each machine cell, select a part family consisting of parts with minimum sum of subcontracting costs subject to the following constraints.

Constraint 1 Processing time available at each machine is not exceeded.

Constraint 2 Number of machines in a cell does not exceed its upper limit or alternatively the dimension (for example the machine length) of a machine cell is not exceeded.

Constraint 3 Some machines have to be included in the same cell because of technological requirements.

The above formulation of GT problem is not only computationally complex, but also involves constraints that are difficult to handle by any of the classical clustering algorithms alone (See Table I in Appendix A). An expert system combined with a clustering algorithm is proposed to be used to solve the GT problem. The expert system developed is based on the knowledge collected from experts, without considering optimization algorithms. The system is based on tandem system architecture where an expert system and algorithm closely interact with each other. The expert system evaluates partial solutions generated by the clustering algorithm and has an impact on its search directions. One of the most tangible advantages of the tandem architecture is a relatively small knowledge base. This is because the computation effort is divided between the expert system and algorithm.

2.3 NOTATION

m : Number of machines

n : Number of parts or items

t_{ij} : Processing time of part j on machine i

c_j : Production volume (some other measure could be used for example, production cost)

T_i : Maximum processing time available on machine i

n_k : Number of machines in cell MC-k

N : Maximum number of machines in any machine cell

The clustering problem is represented by an mxn matrix $[t_{ij}]$ of processing times, where $t_{ij} \geq 0$. This representation is a generalization of the machine-part relationship representation by the binary matrix $[a_{ij}]$, where a_{ij} = 0 or 1. Each entry $t_{ij} > 0$ indicates not only the incidence of machine i and part j, but also the value of the processing time of part j on machine i. Associated with each part j there is the required production volume (C_j) and for each machine i, there is maximum time available (T_i).

2.4 CLUSTERING ALGORITHM

The clustering algorithm is based on two simple observations. (1) A horizontal line h_i drawn through any row i (machine number) of matrix $[t_{ij}]$ indicates parts to be manufactured on machine i. This observation is illustrated in the following matrix.

Part Number

$$[t_{ij}] = \text{M/c No.} \quad \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{bmatrix} 2.0 & & 3.7 & & & 9.8 \\ & 4.0 & & 7.8 & & 9.0 \\ 3.0 & & 2.7 & 8.8 & & \\ 0.5 & & 0.3 & & & 7.8 \\ 9.0 & & 20.0 & & & 0.2 \end{bmatrix} \end{array}$$

The horizontal line h_3 crosses elements (3,1), (3,3) and (3,4) in the above matrix. Parts 1,3 and 4 are manufactured on machine 3.

(2) A vertical line V_j drawn through any column of matrix $[t_{ij}]$ indicates machines to be used for manufacturing part j.

The Algorithm

Step 0 : Set iteration number k = 1

Step 1 : Select machines (rows of matrix $[t_{ij}]^k$, where the superscript k indicates matrix $[t_{ij}]$ at iteration k), which should be included in a machine-cell MC-k because of the requirement imposed by the constraint 3. In the absence of constraint 3, select any machine. Draw a horizontal line h_i through each row of matrix $[t_{ij}]^k$ corresponding to the selected machine(s). The machine(s) indicated by horizontal line (s) are potential candidate(s) for a machine cell MC-k.

Step 2 : For each entry $t_{ij} > 0$ crossed by any of the horizontal lines h_i draw a vertical line V_j. Parts indicated by these vertical lines are potential candidates for a part family PF-k.

Step 3 : Evaluate whether machine cell MC-k and part family PF-k violate any of the constraints 1 to 3. If atleast one of these constraints is violated, then refer to the expert system. If there are no more

crossed once elements of matrix $[t_{ij}]^k$, go to Step 6; otherwise go to Step 4.

Step 4 : For each entry $t_{ij} > 0$ crossed by a vertical line V_j, draw a horizontal line h_i. If there are no more crossed-once elements of the matrix $[t_{ij}]^k$, go to Step 3; otherwise go to Step 5.

Step 5 : For each entry $t_{ij} > 0$ crossed by horizontal line h_l, draw a vertical line V_r and go to Step 3.

Step 6 : Perform the following operations:

(a) Form a machine cell MC-k

(b) Form a part family PF-k

(c) Transform matrix $[t_{ij}]^k$ into $[t_{ij}]^{k+1}$ by removing those rows and columns in $[t_{ij}]^k$ which have been crossed by horizontal and vertical lines.

If $[t_{ij}]^{k+1} \neq \underline{0}$ (where $\underline{0}$ denotes a matrix with all elements equal to zero).

(d) Set iteration number k = k + 1 and go to Step 1 otherwise STOP.

2.5 THE EXPERT SYSTEM

The expert system interacts with the clustering algorithm in Step 3. There are two components of the expert system, the knowledge base and the inference engine.

2.5.1 Knowledge Base

The knowledge base provides rules to solve the problems referred by Step 3 of the algorithm.

Rule 1 IF constraint 1 is violated for machine i

THEN attempt to satisfy this constraint by

- Seeking group setup time on the machine for a possible part family and machine cell combination

IF constraint is still violated

THEN attempt to satisfy by

- Considering alternative process plans for parts produced on machine i

AND if none of the two can satisfy the constraint 1,

THEN solve a corresponding knapsack problem and delete the parts suggested by the solution of knapsack. Place the removed parts in the list of parts to be manufactured by scheduling them separately.

Rule 2 IF constraint 2 is violated for machine cell MC-k

THEN attempt to replace basic process plans with alternative process plans.

AND IF constraint 2 is still violated

THEN remove from this machine cell parts violating this constraint.

Rule 3 IF constraint 3 is violated for machines i, ..., p

AND IF including machines i, ..., p in machine cell MC-k does not violate constraint 2,

THEN include machines i, ..., p in machine cell, MC-k

ELSE remove from MC-k parts which require machines i, ..., p.

It may be noted that if constraint 1 is violated with $[t_{ij}]$ matrix formed from the standard processing time and setup times of conventional production system, the present work has incorporated an approach to satisfy the constraint by seeking the group setup time required by the possible part family combination, on the machine for which the constraint is violated. The group setup time will be generally lower than the sum of individual setup time of each part in the part family on the machine under consideration. Hence it is wise to check constraint 1 incorporating the saving in setup time before attempting to satisfy by seeking alternate process plan(s) or by deleting parts using knapsack algorithm.

Discussion of the Rules

Rule 1 To fire Rule 1, the inequality

$$\sum_j t_{ij} \leq T_i$$

is checked for each horizontal line h_i. If the inequality is violated, one of the three approaches can be applied. The first approach takes advantage of reduced setup time with grouping. The individual machine setup times for each part machined on the machine will be displayed and the corresponding group setup time will be taken.

The second approach is based on alternative process plans. If there is any alternative process plan for any of the items machined on the machine, it considers the process plan and attempts to satisfy the constraint by replacing the basic process plan with alternate process plan.

However, if none of the above approaches can be applied, deleting parts from the machine is required. These parts are to be manufactured by scheduling them separately or may be subcontracted. The deleting of parts is rationally done by solving a corresponding knapsack problem. Parts not included in the solution to the following knapsack problem are to be deleted from the machine i:

$$\text{Max} \sum_j c_j \, x_{ij}$$

$$\text{s.t.} \quad \sum_j t_{ij} \, x_{ij} \le T_i$$

$$x_{ij} = 0,\ 1 \ \textit{for} \text{ all } j$$

Rule 2 If constraint 2 is violated, i.e. the number of machines in a cell exceed the maximum number of machines permitted in a cell, the machines required by smallest number of parts in the cell are eliminated.

Rule 3 To illustrate Rule 3 assume, with the following matrix that:

(a) The following pairs of machines have to be included in the same machine cell

Machines 1 and 2

Machines 4 and 5

(b) $N = 3$

(c) h_4 and v_3 are the last drawn lines

$$[t_{ij}]^k = \begin{array}{ccc} & \begin{array}{cccccc}1&2&3&4&5&6\end{array} & \\ \begin{array}{c}1\\2\\3\\4\\5\end{array} & \begin{bmatrix}1&1&&&&\\&1&1&&1&\\1&&&&&\\&&1&1&&1\\&&&1&&1\end{bmatrix} & \begin{array}{c}h_1\\h_2\\ \\h_4\\ \end{array} \\ & \begin{array}{cccccc}&v_2&v_3&&&\end{array} & \end{array}$$

Horizontal line h_4 indicates that machine 4 is to be included in the current machine cell MC-k. Including machine 5 in MC-k would violate assumption (b) i.e. constraint 2. Therefore, an alternative process plan for part 3 is considered. Assuming that there does not exist for part 3 an alternative process plan without using machines 4 and 5, machine 4 and corresponding parts including part 3 are removed from current cells.

2.5.2 Inference Engine

One of the greatest advantages of the tandom architecture is the simplicity of inference engine. The inference engine of KBGT uses forward chaining inference strategy. It simply matches the data concerned with the IF part of a rule. If the match is successful, the rule is fired. In the present system, the role of inference engine is trivial due to the tandom architecture.

2.5.3 Flow Chart

Fig. 2.1 shows the flow diagram of expert group technology system.

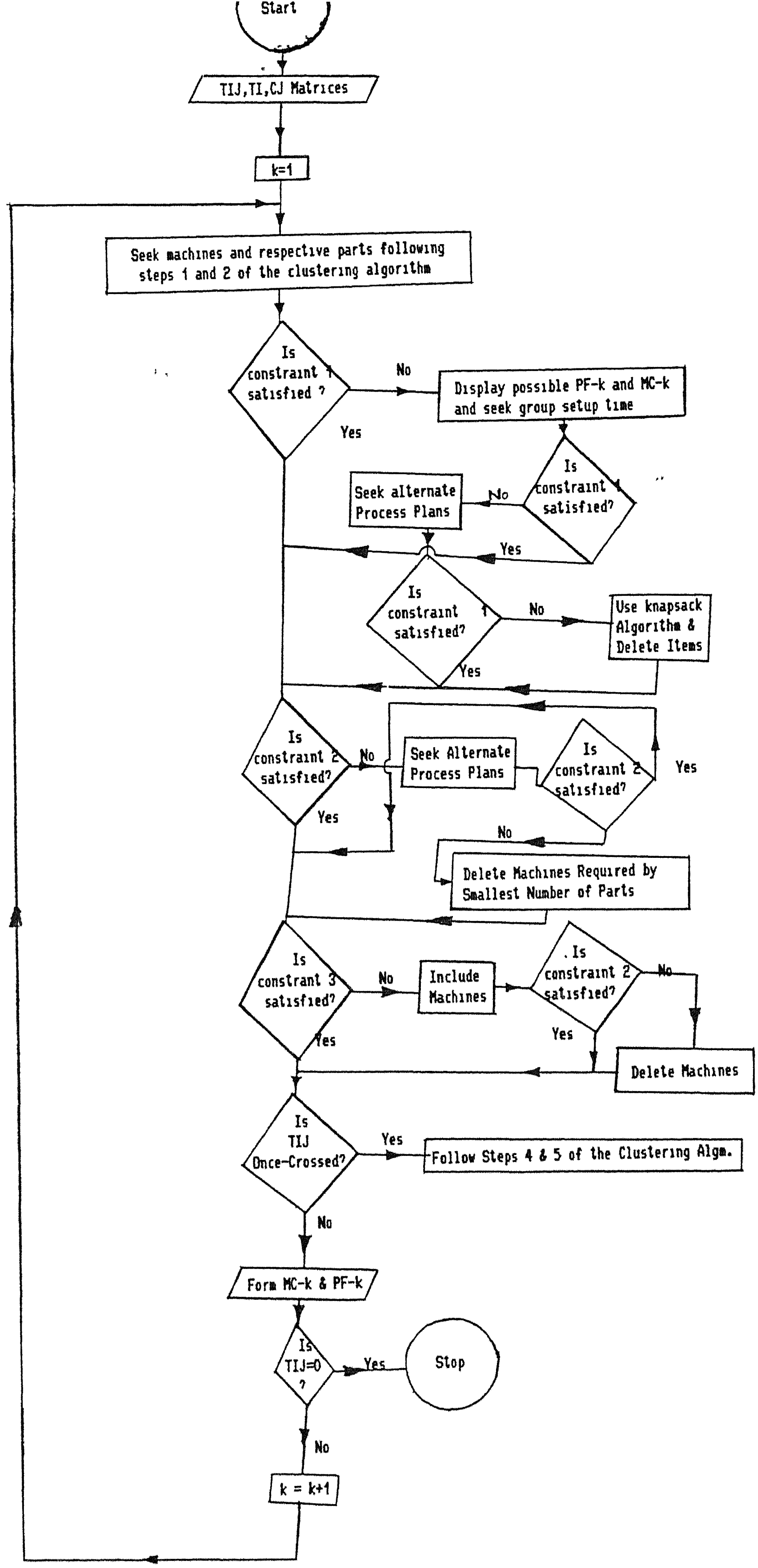


Fig. 2.1: Flow diagram of the Expert GT System.

In this chapter, the knowledge based system used to solve group technology problem is presented. The machine cells and part families obtained using the KBGT are used in the development of master production schedule planning with GT.

CHAPTER III

MASTER PRODUCTION SCHEDULING IN CIMS ENVIRONMENT

3.1 INTRODUCTION

The importance of developing a feasible master production schedule (MPS) which can be executed on the shopfloor of a production system has been discussed in Sec.1.2.1 of Chapter I. Developing a master production schedule involves a decision making at different levels in a hierarchial structure. There is a vast literature available for developing a feasible MPS in a conventional flow shop or job shop layout production environment. For a quick detailed review of steps in developing feasible MPS in a conventional production system, one may refer to Gessener [10], S.K. Gupta, [11], Tersine [2]. In this chapter, we discuss methodology for developing feasible MPS in cellular manufacturing layout. The aspects of developing feasible MPS are as important as integration of MRP and GT by group scheduling, which is a matter of concern for the next chapter. We start with a brief introduction to the production system environment, the nature of demand and assumptions made in the development of MPS.

3.2 MANUFACTURING ENVIRONMENT

We consider a production system in which a number of products are manufactured. Each product is assembled from several dependent items, which form a well defined product structure. That is, we assume that MPS can, in its entirety, be stated in terms of 'bill of item numbers'.

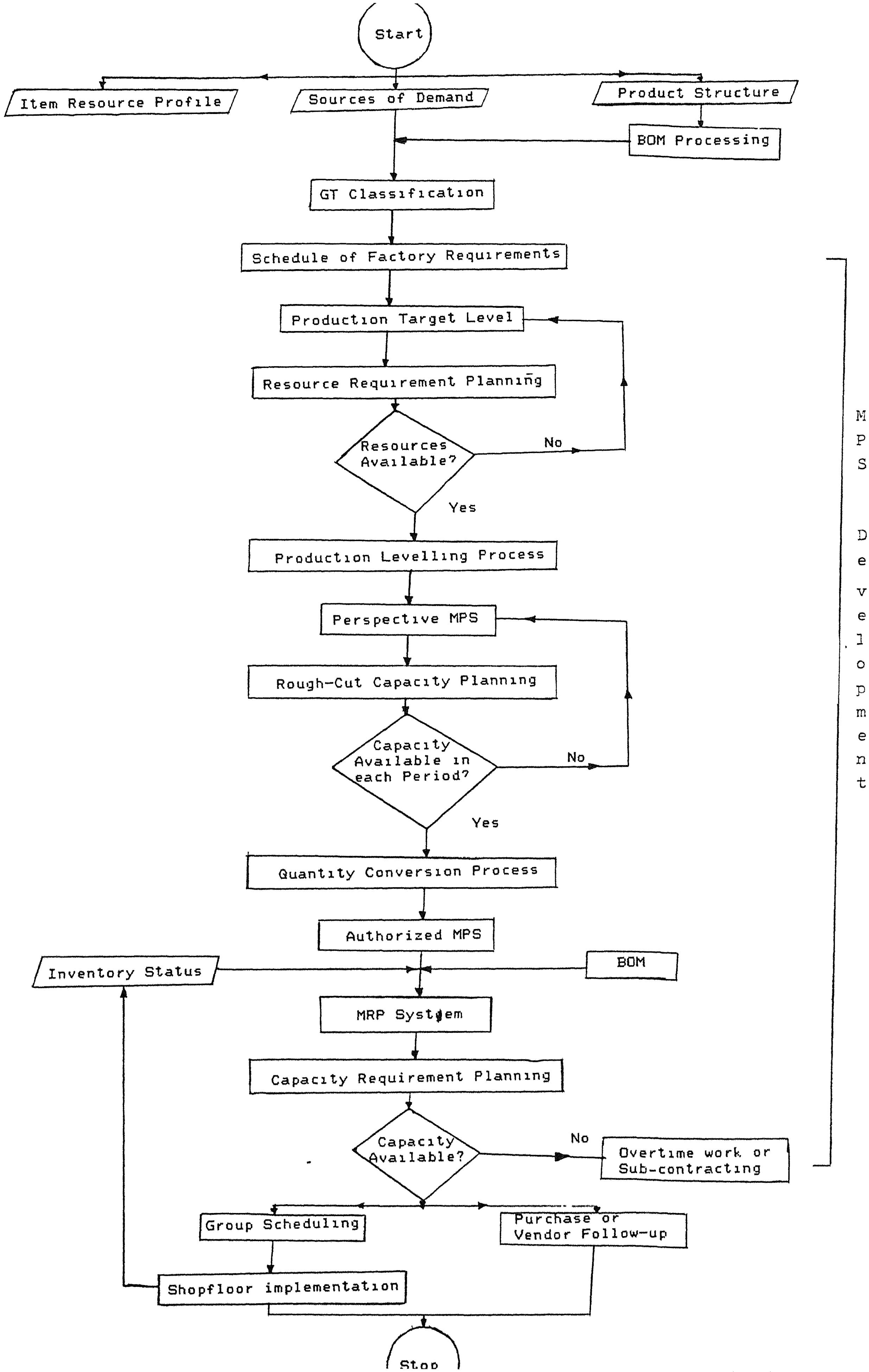
We consider the production system of cellular layout comprising of groups of machine cells and part families. Associated with each part family will be a group setup time on each machine required by any of the items in the part family. The items which are rejected out of the production system by the knowledge based system described in the earlier chapter due to the shopfloor constraints considered while forming part family and machine cell combinations are considered to be manufactured by scheduling them separately. For highlighting the advantages of a cellular layout over a conventional layout, the MPS development in a conventional layout is also considered in parallel. The major assumptions made in the development of MPS are (a) Group setup time and individual setup time are sequence independent at all work centers, (b) Leadtimes for production of components and procurement of materials are considered deterministic, (c) Overtime work or subcontracting is assumed to be possible to meet the capacity requirement at the short term capacity requirement planning level. It is not considered while preparing MPS at strategic level. However there is a facility to change capacity available at the level of long term resource requirement planning.

3.3 MPS DEVELOPMENT

The flow chart of the system developed for an integrated MRP and GT approach with feasible MPS is as shown in Fig. 3.1. The figure clearly shows the various hierarchial decisions involved in the preparation of MPS, which can be stated as:

1. Resource Requirement Planning (RRP)
2. Rough Cut Capacity Planning (RCCP)
3. Material Requirements Planning (MRP)
4. Capacity Requirements Planning (CRP)

The basic inputs required for the preparation of MPS are the demands of end items (products) converted into period wise schedule requirements over the planning horizon called factory schedule requirements, resources available on the shopfloor part families with group setup times in the cellular production system, product structure of each product, and resource profile of each item. Product structure is the structured diagram of items assembled to form an end item. The various levels of the product structure and items in each level are coded following the low-level coding, which is discussed in Sec. 3.3.3.2. Bill of material processing involves computation of number of units of each item required for producing a unit end item, from the product structure. Resource profile is the requirement of resources by an item. It contains both setup time and processing time required by an item on each of the resources required by it. In this discussion, we consider resource as machine. But it could also be man power or a combination of them.


Start
Item Resource Profile
Sources of Demand
Product Structure
BOM Processing
GT Classification
Schedule of Factory Requirements
Production Target Level
Resource Requirement Planning
Resources Available?
No
Yes
Production Levelling Process
Perspective MPS
Rough-Cut Capacity Planning
Capacity Available in each Period?
No
Yes
Quantity Conversion Process
Authorized MPS
Inventory Status
BOM
MRP System
Capacity Requirement Planning
Capacity Available?
No
Overtime work or Sub-contracting
Group Scheduling
Purchase or Vendor Follow-up
Shopfloor implementation
Stop
MPS Development

The following sections describe the above four modules viz. RRP, RCCP, MRP and CRP in detail.

3.3.1 RESOURCE REQUIREMENT PLANNING

The Resource Requirement Planning (RRP) uses operations data at end item level i.e. it requires aggregate standard processing time and group setup time for each end item at all the work centres it is processed. These aggregate data are obtained from product structure, resource profiles and group setup time data. RRP constitutes production level target setting, calculation of resources required to support the target production and testing the resources required against resources available. The initial production level targets are set at the average of factory schedule requirements of the product over the planning horizon. These production targets for each product are tested against resources available. If the resources available are not sufficient then either the production targets or the resources available are adjusted to make the production plan feasible. The outputs of RRP are feasible production targets for each end product. The feasible production targets are smoothened in the production levelling process.

The production levelling process reschedules the production of each product in each period so that production in minimum number of periods deviates from target production level, ensuring that minimum amount of inventory is carried from one period to the next. The output of the production levelling process is termed as

Perspective MPS and is inputted to the rough cut capacity planning system.

The following section describe the resource testing and production levelling aspects of RRP.

The notation described below is used in the following discussion.

Notation

P : number of periods in the planning horizon.

m : number of part families (or groups).

n_p : number of products or end items.

n : total number of items in the system.

D_{lq} : forecasted demand of product 'l' in planning period q for all $l = 1$ to n_p and $q = 1$ to P.

Q_{lq} : quantity of product l scheduled for planning period q for all $l = 1$ to n_p and $q = 1$ to P.

E_k : efficiency of work center k (= number of productive hours/actual available hours).

F_k : failure allowance of work center, k (= standard hours available/actual hours available (> 1)).

N_{lj} : number of units of item 'j' required by a unit of product l (obtained from bill of material processing of product structure).

w_q : number of working days in planning period q.

H_k : availability of work center k in number of hours per day.

p_{jk} : time in minutes/item of processing time required by item j on work center k, for all j = 1 to n.

X_{jk} : time in hours of setup time required by item j in a conventional production system on work center k.

S_{ik} : group setup time in hours required by part family i on resource k.

T_{cl} : production target level of product 'l' in conventional production system.

T_{gl} : production target level of product 'l' in cellular production system.

N_k : number of machines of work center k.

C : shop load factor (= maximum loading possible in the shopfloor considering congestion, material handling etc.

3.3.1.1 Resource Testing

It is a comparison of resources required for executing the MPS with the actual available resources in the shopfloor. It is carried out as discussed in the following sections.

Methodology

$$T_{gl} = T_{cl} = \sum_{0=1}^{P} D_{lo}/P \qquad \text{for all } l = 1 \text{ to } n_p$$

Total variable processing time in hours of work centre k required in conventional production system (V_{ck}) or cellular production system (V_{gk})

$$V_{gk} = V_{ck} = \sum_{l=1}^{n_p} \sum_{j=1}^{n} T_{cl} * p_{jk} * N_{lj} / (60 * E_k).$$

Total individual setup time of work centre k required in hours in a conventional production system

$$= Y_{ck} = \sum_{j \in J} X_{jk} ,$$

where J is a set of {1,...,n} components, which are required by any of the product l for all l = 1 to n_p.

Total group setup time required on work centre k in hours in a cellular production system

$$= Y_{gk} = \sum_{i \in I} S_{ik}$$

where, I is a set of part families {1,..,m} atleast a component of the part family is required by any of the product l for all l = 1 to n_p.

Total individual setup time required by the rejected items

$$= Y_{rk} = \sum_{r \in R} X_{rk}$$

where R is a set of all rejected items by expert GT system.

Total time in hours of work center k required in conventional system

$$= U_{ck} = (V_{ck} + Y_{ck}) * F_k$$

Total time in hours of work center k required in cellular system

$$= U_{gk} = (V_{gk} + Y_{gk} + Y_{rk}) * F_k$$

average number of days/period over the planning horizon

$$= \bar{w} = \frac{1}{P}\sum_{q=1}^{P} w_q$$

Number of work centres of 'k' required in a conventional production system

$$= N_{ck} = \frac{U_{ck}}{\bar{w} * H_k}$$

Number of work centres of 'k' required in a cellular production system

$$= N_{gk} = \frac{U_{gk}}{\bar{w} * H_k}$$

The resource requirements are computed for each work centre. The overload and underload work centres will be identified by comparing the required number of machines with available number of machines.

3.3.1.2 Production Targetting

Before production targetting is established, the resource availability may be altered. With the existing machines, the production target adjustment for each product will be arrived as follows.

Loading factor without GT for work centre k

$$= Z_{ck} = \frac{N_k * \bar{w} * H_k}{U_{ck}}.$$

Loading factor with GT for work centre k

$$= \quad Z_{gk} \quad = \frac{N_k * \bar{w} * H_k}{U_{gk}}.$$

Let

$$Z_c^* = \min_{k \in K} (Z_{ck}) \text{ where K is set of all work centres.}$$

$$Z_g^* = \min_{k \in K} (Z_{gk}) \text{ where K is set of all work centres.}$$

The amount of product 'l' scheduled in each period is multiplied by Z_c^* and Z_g^* in conventional and cellular layout systems respectively to obtain the targetted production of demand in each period.

3.3.1.3 Production Levelling

The production levelling is to smoothen the demand fluctuations in different periods which results in uniform capacity requirement. An algorithm discussed by SK Gupta [11] has been adopted to level the target production demands generated in both the cases. The algorithm evaluates the ending inventory for each product in each period and attempts to minimize the inventory carrying by adjusting the production level in some periods. The levelled production is termed as 'Perspective MPS' and it forms an input to rough cut capacity planning (RCCP).

The following section discusses the RCCP module.

3.3.2 ROUGH CUT CAPACITY PLANNING (RCCP)

RCCP deals with relatively shorter time spans compared to RRP. Usually it is done for every planning period. The purpose

is to test the resource availability against short term requirements. Due to the complexity involved in carrying out RCCP for each resource in each period, initially critical work centres will be identified considering the worst period case in the planning horizon. The products requiring the critical work centres are planned in detail in each period.

The following section details the procedure for identifying critical work centres.

3.3.2.1 Identification of Critical Work Centres

Let an addition of suffix 'q' to the notation mentioned earlier stand for the quantities in planning period 'q'. Let R_{clq} and R_{glq} be the perspective MPS for period 'q' of product l in conventional and cellular layout respectively.

Total individual setup time on work centre k in hours required in period 'q' in a conventional production system

$$= Y_{ckq} = \sum_{j \in J} X_{jk}.$$

where J is a set of items (1,..., n), which are required by any product l, manufactured in period 'q' for all l = 1 to n_p.

Total group setup time required in hours in planning period in cellular layout

$$= Y_{gkq} = \sum_{i \in I} S_{ik}$$

where I is a set of part families (1,..,m), atleast a component of part family is required by any of the product 'l' manufactured in

period 'q' for all $l = 1$ to n_p.

Setup time required by rejected items in hours in period 'q'

$$= Y_{rkq} = \sum_{r \in R} X_{rk} \text{ where R is a set of rejected items.}$$

Variable processing time required in conventional production system on work centre k in period 'q'

$$= V_{ckq} = \sum_{l=1}^{n_p} \sum_{j=1}^{n} R_{clq} * p_{jk} * N_{lj} / (60 * E_k).$$

Variable processing time required in cellular production system on work centre k in period 'q'

$$= V_{gkq} = \sum_{l=1}^{n_p} \sum_{j=1}^{n} R_{glq} * p_{jk} * N_{lj} / (60 * E_k)$$

Total time required in hours on work centre k in period q in a conventional layout,

$$U_{ckq} = V_{ckq} + Y_{ckq}.$$

Total time required in hours on work centre k in period q in a cellular layout,

$$U_{gkq} = V_{gkq} + Y_{gkq} + Y_{rkq}$$

Over the planning horizon, the worst case would be considering the combination of the period with the maximum amount of each product to be produced and the period in which there is minimum available time.

The worst case estimated capacity fraction in conventional production system

$$= O_c = \left[\sum_{j=1}^{n} \sum_{l=1}^{n_p} p_{jk} R_{cl}^{mx} * N_{lj}/(60 * E_k) + Y_{ck}^{mx} \right] / H_k * \bar{w}^{mn}$$

The worst case estimated capacity fraction in cellular production system

$$= O_g = \left[\sum_{j=1}^{n} \sum_{l=1}^{n_p} p_{jk} R_{gl}^{mx} * N_{lj}/(60 * E_k) + (Y_{gko} + Y_{rko})^{mx} \right] / H_k * \bar{w}^{mn}$$

where

$$R_{cl}^{mx} = \underset{q \in P}{\text{Max}} (R_{clq}),$$

$$R_{gl}^{mx} = \underset{q \in P}{\text{Max}} (R_{glq}),$$

$$w^{mn} = \underset{q \in P}{\text{Min}} (w_q),$$

$$Y_{ck}^{mx} = \underset{q \in P}{\text{Max}} (Y_{ckq}),$$

$$(Y_{gkq} + Y_{rkq})^{mx} = \underset{q \in P}{\text{Max}} (Y_{gkq} + Y_{rkq}).$$

The work centres having O_c or O_g (as the case may be) less than shop load factor are eliminated from further consideration. The shop load factor, depending on congestion, material handling etc. in the system may range from 0.65 to 0.98, with higher values being preferred. The following section enunciates the production adjustment called upon by the critical work centres.

3.3.2.2 Production Adjustment

On each critical work centre, the production demand must be adjusted to make it feasible to execute with the available resources. There are two methods for doing this, (a) Reduction by same proportion, and (b) Reduction by priority.

Reduction by Same Proportion

Consider any of the critical work centre k.

Production level adjustment in conventional production system on critical work centre k in period q,

$$Z_{ckq} = (CH_k w_q N_k - Y_{ckq}) / V_{ckq}$$

Production level adjustment in cellular production system on critical work system k in period 'q',

$$Z_{gkq} = (CH_k w_q N_k - Y_{gkq} - Y_{rkq}) / V_{gkq}.$$

The above process is repeated for all critical work centres in planning period 'q' and effective capacity adjustment factor for the entire system for planning period 'q' in conventional production system,

$$Z^*_{cq} = \min_{b \in B_c} (Z_{cbq}),$$

where B_c is a set of all critical work centres in conventional production system.

Similarly, the adjustment factor in cellular production system

$$Z^{*}_{gq} = \min_{b \in B_g} (Z_{gbq}),$$

where B_g is a set of all critical work centres in cellular production system. If the effective capacity adjustment factor is greater than 1.0, the effective capacity production is greater than the requested production. If the value is less than 1.0, the requested production cannot be met.

The effective production level for time period o is found by multiplying the resulting Z^{*}_{cq} and Z^{*}_{gq} with respective requested production levels.

Priority Rule

It reduces the production of only selected products based on a priority index. The product with highest priority index is selected for reducing the production and the index is given by,

Priority index for period 'q' in conventional layout,

$$= (R_{clq} - T_{cl})/D_{lq}.$$

Priority index for period 'q' in cellular layout,

$$= (R_{glq} - T_{gl})/D_{lq}$$

Let 'p' be the product selected by above criterion for cellular manufacturing system. Also assume 'p' is processed on a set of work centres denoted by W. For each 'w' work centre considered in W, the production adjustment factor is calculated using the following relationship.

$$A_{wpq} = (\sum_{j \in J} p_{jw} * R_{gpq} / E_w + C * H_w * w_q - U_{gwq})/(\sum_{j \in J} p_{jk} R_{gpq} / E_w)$$

where, J is set of items required by product 'p'. Effective adjustment factor $A_{*po} = \min_{w \in W} \{A_{wpo}\}$,

The modified production schedule for product 'p' is max $\{A_{*po} * R_{gpo}, T_{gp}\}$. The process of selecting the product and reducing the production is repeated till A_{*po} becomes equal to or greater than 1.0 or the production of products has been reduced to effective production target level. If the production of all the products have been reduced to target production level and value of A_{*po} is still less than 1.0 then production level is reduced by using first option i.e. by reducing the products proportionately.

Similarly, it is repeated for the conventional production system.

3.3.3 MATERIAL REQUIREMENTS PLANNING (MRP)

In this section, we present the concepts associated with MRP. The input to MRP will be authorized MPS developed by RCCP, bill of materials and inventory status data. The MPS is a specification of end item requirements in each time bucket. Bill of materials, derived from processing of product structure, consists of number of units of items required by a unit of end item. Inventory status file contains onhand quantity, safety stock, allocated quantity, scheduled receipts and independent

demand (excluding end items) for each of the items. Before describing the processing logic of MRP, let us understand the assumptions made in the system.

3.3.3.1 Assumptions

(a) Master production schedule can in its entirety, be stated in terms of end products i.e. a dependent demand is existing and a well defined product structure is there.

(b) Each item can be uniquely identified by its code. The low level code adopted in the system is discussed in Sec. 3.3.3.2.

(c) Lead times for all the items are deterministic.

(d) In determining timing of gross requirements, the MRP procedure assumes that all components of an assembly must be available at the time an order for that assembly is to be released to the factory.

(e) Disbursement and usage of component materials are assumed to be discrete.

(f) Processing dependencies (for e.g. setup time) one not existing.

3.3.3.2 MRP Processing

Quantity Conversion

This is conversion of period-wise demands into bucket-wise demands. This is done proportionately to the number of days in period and bucket, i.e. daily demand rate is multiplied by number of days in the bucket. This is called 'work day approach' by Gessener [10].

Low-level Coding

The low-level coding not only enables an item to be identified uniquely but also reduces the data processing complexity. There may be recurrence of gross requirements for a given item, during the requirements-computation (explosion) process due to the fact that the item's several parents are on different levels. There are two cases: an item may exist on different levels in the structure of different end items which use it in common or may exist on different levels in the structure of one end item. In a given case, both of these conditions may exist at the same time. The problem here is one of having to reprocess and re-net at every recurrence of gross requirements stemming from parent items that may appear on multiple level. This problem is solved by low-level coding technique. Low level coding emphasizes the fact that when a component appears at more than one level, it must be assigned to its lowest level i.e. the level farthest down the product structure. A sort from highest level to lowest level and sequential processing of requirements computation will ensure level by level process to produce correct results.

3.3.3.3 MRP Outputs

The MRP takes MPS for end items and determines the gross quantities of all lower level items required by 'exploding' the end item product structure into the lower level items. The explosion results in 'what' items are required as well as 'how many'. The net requirements are determined by subtracting

scheduled receipts and on-hand quantity from gross requirements. The net requirements are to be covered by planned receipts to enable scheduling the manufacture or procurement of the items. To generate planned receipts the system must determine the order quantity, timing of required order completion (due date) and the timing of order release. These tasks are accomplished by lot sizing and time phasing. Lot sizing determines the order quantity based on economics and when the order must be received. There are number of lot sizing techniques generally discussed in any MRP literature. But none of the techniques available are perfect and their performance largely depends on input parameters. For this reason, a number of techniques which are used in practice are incorporated and they are, (a), Lot for lot, (b) Fixed order quantity, (c) Minimum Order quantity, (d) EOQ, (e) Modified EOQ, (f) Fixed period requirements, (g), Period order quantity, (h) Least total cost, (i) Least unit cost, (j) Modified least total cost and (k) Wagner-Whitin algorithm.

For a detailed review of the lot sizing techniques, one may refer Orlicky [1], Wagner, Whitin [12].

The planned receipts will be time-phased by offsetting the lead time to obtain planned order releases.

3.3.4 CAPACITY REQUIREMENT PLANNING (CRP)

The purpose of CRP is to test whether the available resources can execute the bucket-wise planned order releases generated by

MRP or not. And also to identify overload work centres in a bucket and graphically depict the capacity requirements over the MRP exploded number of buckets to enable short-term measures such as providing overtime, running additional shifts, transferring resources etc. to be taken. The MRP generated planned order releases and item resource profile forms the input to CRP. The output of CRP will be capacity plan (Time phased capacity available vs. capacity required) for each work centre.

3.4 EVALUATION OF ALTERNATE MPS

The capacity plan and material plan generated depend on the MPS, lot sizing technique inputted to MRP, lead time and route sheet of items.

If the capacity demanded by CRP is infeasible to execute with the available provisions such as hiring, overtime etc., the MPS or lot-sizing must be changed. To change MPS, shop load factor supplied at RCCP stage is altered. If the capacity plan is highly fluctuating and erratic, it is advised to try out different lot sizing techniques for scheduling the planned orders.

The next chapter discusses the methodology adopted for integrating MRP and GT and explains the group scheduling algorithm employed for the purpose.

CHAPTER IV

GROUP SCHEDULING

4.1 INTRODUCTION

The definition and basic concepts of "Group Scheduling" are discussed in Chapter I. Most group scheduling algorithm assume that all items for the operation under consideration are available at the beginning of the scheduling stage. That is, most group scheduling algorithms do not consider the very practical, and important time-phased aspects of item production. Thus, it is necessary to develop an integrated method for combining the GT concept and material requirements planning (MRP). But there is very little work done in this area. A few pioneers in group scheduling proposed a skeleton structure for integrating GT and MRP (Sato, N. et al [13]). A case study was performed in order to evaluate the effectiveness of the integrated GT and MRP technique in the group scheduling problem under the criterion of makespan. The result of the case study showed that significant opportunities for manufacturing costs are possible by introducing group scheduling in a production system where there is a separate introduction of GT and MRP. Others who support the integration of MRP and GT are New [14] and Suresh [15].

In the following section, the methodology proposed by Sato et.al. [13] is outlined.

4.2 METHODOLOGY FOR INTEGRATING MRP AND GT

A procedure for integration of GT and MRP is described as a series of following steps.

Step 1 Gather the data normally required for both the group technology and MRP concepts (that is parts and their description, machine capabilities, a break down of each final product into its individual items, a forecast of final product demand, etc.)

Step 2 Use group technology to determine part families.

Step 3 Use MRP to assign items to a specific time period.

Step 4 Arrange the item time-phased assignments of Step 3 according to the part family groups of step 2.

Step 5 Use a suitable group scheduling algorithm to determine the optimal schedule for all those parts within a given group for each time period.

In the earlier chapters, the relevant topics concerning step 2 and step 3 of the above procedure are discussed in detail.

In the following section, a heuristic group scheduling algorithm (step 5) implemented in the system is discussed.

4.3 GROUP SCHEDULING ALGORITHM

The heuristic algorithm implemented for scheduling the planned order releases of material requirements planning for manufactured items, considers the due date constraints for the

items as established by the manufacturing lead times used in MRP. Under due date constraints in scheduling problems, time-dependent penalties are assessed on late jobs but no benefits derive from completing jobs early. That is to say, in general the penalty costs are associated with tardiness. Besides penalty costs, some other reasons for using tardiness criterion under due date constraints, are discussed by Conway et al [16]. Therefore scheduling criterion of minimizing total or mean tardiness is chosen for group scheduling. The complexities of tardiness criterion are mentioned in Chapter I. There are a few optimizing algorithms (Nakamura et al [17]) proposed, but they are not practical owing to their severe computational requirements. However, the heuristic algorithm developed by Cho Kyu Kab [9], is reported to have produced near optimal solutions efficiently. The algorithm is capable of handling large problems and its computational requirements are very low as compared to that of optimizing algorithms.

In the present implementation, the heuristic algorithm is used to schedule the item assignments of MRP to minimize total tardiness. The following sections briefly review the algorithm implemented.

4.3.1 Assumptions

The following assumptions are made in the development of heuristic algorithm.

1. Parts or jobs (parts to be made are called 'jobs') are to be processed on a manufacturing system consisting of K different stages or machines, through which a piece of raw material is converted to a finished product. The stage index is denoted by $k(k = 1,2,...K)$ and the machine at stage k is denoted by M_k.

2. A set of N multiple-operation jobs, classified into M different groups, are available for processing at time zero. The group index is denoted by i ($i = 1,2,.., M$) and n_i jobs are included in group i (G_i). The job index is denoted by $j(j = 1,2,...,n_i)$. Therefore, it is clear that

$$\sum_{i=1}^{M} n_i = N$$

3. Job processing time consists of the job setup time and direct processing time of the job. Job setup times are independent of job sequence and consequently are assumed to be included in the job processing times.

4. Group processing time consists of group setup time and the sum of the job processing times contained in each group. It is assumed that the group setup time is independent of group sequence.

5. No precedence relationship exists among groups and among jobs in each group.

6. Job preemption is not allowed.

7. No passing of group and job is allowed.

8. Group setup times and job processing times on each stage are known. Each job possesses a known due date.

4.3.2 Notation

The following is the notation used

[ ] : denotes position in sequence

J_{ij} : job j in group i

p_{ij}^{k} : processing time required by J_{ij} on machine k

S_{i}^{k} : group setup time required by G_i on stage ki

d_{ij} : due date of job J_{ij}

C_{ij} : completion time of J_{ij}

σ : set of groups which are sequenced.

σ' : complementary of σ

$|\sigma|$ and $|\sigma'|$: number of groups in σ and σ' respectively

F_{ij} : flow time of J_{ij}

q_{σ}^{k} : the completion time of the last job of the last group in σ on stage M_k

q_{σ} : q_{σ}^{K} the completion time of the last job of the last group in σ on last stage M_K

Q_{c}^{k} : group processing time of group i on machine k

$$= S_{i}^{k} + \sum_{j=1}^{n_i} p_{ij}^{k}$$

P_{ij} : p_{ij}^{K}, processing time of J_{ij} on the last machine

4.3.3 Objective Function

The objective function for the problem may be given as

$$\min T = \min_{s \in S} \sum_{i=1}^{M} \sum_{j=1}^{n_i} f(C_{ij})$$

where

s = a group schedule;

S = the set of $M! \sum_{i=1}^{M} (n_i!)$ group schedules

$f(C_{ij}) = \max(0, C_{ij} - d_{ij})$

4.3.4 Heuristic Procedure

Step 1 Initialize $\sigma = \phi$, $\sigma' = \{1,2,3..., M\}$

Step 2 Determine job sequence for every group i in σ'.

(i) Set $A_i = \phi$ and $B_i = \{1,2,..., n_i\}$

(ii) If $|B_i|$, go to (iii) otherwise, sequence the remaining job in the n_i-th position and go to Step 3.

(iii) Compute α_{ij} (a relative measure of job tardiness) for all jobs in B_i as follows.

$$\alpha_{ij} = \begin{cases} (LB\,(F_{ij}) - d_{ij})) \mid (LB\,(F_{ij}) - q_\sigma - P_{ij}) & \text{if } d_{ij} < LB\,(F_{ij}) \\ 0 \text{ otherwise} & \end{cases}$$

where

$$LB\,(F_{ij}) = \max_{1 \le k \le K} (LB\,(F^k_{ij})$$

$$LB\,(F^k_{ij}) = q_\sigma + P^k_{ij} + \sum_{\substack{m \in B_i \\ m \ne j}} P^k_{im} + \sum_{\substack{l \in \sigma' \\ l \ne i}} Q^k_l$$

$$+ \min_{\substack{l \in \sigma' \\ 1 \le h \le n_l}} \{ \sum_{k=k+1}^{K} p^k_{lh}, \sum_{k=k+1}^{K} p^k_{im} \}$$

for $1 \le k \le K-1$

and $$= q_{\sigma} + P_{ij} + \sum_{\substack{m \in B_i \\ m \neq j}} p_{im}^{K} + \sum_{\substack{l \in \sigma' \\ l \neq i}} Q_l^K \quad \text{for } k = K$$

(iv) For job j^* such that $\alpha_{ij^*} = \max_{j \in B_i} \alpha_{ij}$. If tie values for α_{ij^*} occur, select job j^* with the earliest due date.

(v) Sequence job j^* in the $(|A_i| + 1)$-th position and remove it from B_i and go to (ii).

Step 3 If $|\sigma'| > 1$, go to Step 4. Otherwise schedule the remaining group from σ' to the last position of the group sequence and go to Step 8.

Step 4 Compute α'_{ij} for every job in each $G_i \in \sigma'$ according to the determined job sequence in step 2 as follows.

$$\alpha'_{ij} = \begin{cases} LB(F_i) - d_{ij})/(LB(F_i) - C_{ij}), & \text{if } d_{ij} < LB(F_i) \\ 0 & \text{otherwise} \end{cases}$$

where

$$LB(F_i) = \max_{1 \le k \le K} \{LB\ (F_i^k)\}$$

$$LB(F_i^k) = q_{\sigma_i}^k + \sum_{\substack{l \in \sigma' \\ l \neq i}} Q_l^k + (\min_{\substack{l \in \sigma \\ 1 \le h \le n_l}} \sum_{k=k+1}^{K} p_{lh}^k) \quad \text{for } 1 \le k \le K-1$$

$$= q_{\sigma_i} + \sum_{\substack{l \in \sigma' \\ l \neq i}} Q_l^K \quad \text{for } k = K$$

and $LB(F_i{}^k)$ denotes a lower bound on makespan of G_i under a given partial sequence σ_i.

Step 5: Compute α_i for each group in σ' as follows.

$$\alpha_i = \frac{1}{n} \sum_{j=1}^{n_i} \alpha'_{ij}$$

where $n = n_i$ - (number of jobs not tardy in group i)

$\alpha_i = 0$, if all jobs in group i are not tardy.

Step 6 Find group i^* such that $G_i{}^* = \{i^* | \alpha_i{}^* = \max_{i \in \sigma'} \alpha_i\}$. If there are tie values of $\alpha_i{}^*$, then select group i^* which has the largest number of jobs in the group. In general, find group i such that

$$G_i{}^* = \{i^* | \alpha_i{}^* = \max_{i \in \sigma'} \alpha_i \text{ and } n_i{}^* = \max_{i \in \sigma'} n_i\}$$

Step 7 Schedule $G_i{}^*$ in the $(|\sigma| + 1)$ th position and compute $T_i{}^*$. Then remove it from σ' and go to Step 2.

Step 8 STOP

The heuristic procedure is relatively simple and easy to apply to large-size problems. The number of iterations required to determine the group sequence is (M-1), and the number of iterations required to determine job sequence in each group is (n_i-1). In each iteration, for determining both group sequence and job sequence, the size of the problem is reduced. The size of groups and that of jobs at the first iteration are M and N respectively. In the second iteration group size and job size become M-1 and $N-n_{[1]}$, respectively and at the third iteration, then become M-2 and $N - (n_{[1]} + n_{[2]})$, and so on. In general the

size of group and that of jobs at i-th iteration are M-i+1 and $N - \sum_{j=1}^{i} n_{[j-1]}$, respectively, where $n_{[0]} = 0$ and $i = 1,2,\ldots, M$.

CHAPTER V

SYSTEM DESIGN AND IMPLEMENTATION

5.1 INTRODUCTION

This chapter deals with database design aspects and other implementation features of the system developed. The system is implemented in TURBO PASCAL version 4.0 on PC XT/AT. PASCAL is used to take advantage of its file handling capability, facility to develop long programs owing to its structure thus enabling easy debugging. And also version 4.0 has capability to make pascal units and compile a segment of the program (i.e. a unit) separately. The compiled units can be activated from the other programs in much less time. This not only enables to reduce the compilation time required while developing a large program but also makes it possible to develop large programs exceeding 64 K. Moreover, the compiled version of the program (.EXE) can be run from disk operating system (DOS) environment without using any system files.

The following sections discuss some of the major design aspects incorporated in the system.

5.2 DATABASE DESIGN

Database integrity, consistency are a must for obtaining correct results with MRP. Other design issues which are of major

importance in implementing the system are quick accessibility, size of the data file i.e. the number of fields in a record and number of files used. Quick accessibility ensures faster data searching. Integrity, validity and minimum repetition of data (i.e. no redundancy) are ensured by the process of normalization. In the present work, the database has been normalized to third normal form. Data in a file is retrieved through key fields and data in various files are linked together on foreign key fields to search the data from more than one file. To reduce the time taken in loading writing closing the file, which are carried out frequently, the file size i.e. number of fields in a record has been kept to minimum possible. Conflicting this desirability is number of files, which should not be too large for it would create problem of opening and closing files frequently. The database has been designed considering these points.

5.3 DATA FILES

The following data files are designed following the principles of database design enunciated in previous section. Brief description of the fields maintained in each file are described below.

File Name	Key Field(s)	Rec. Size (bytes)	Remarks
Actual .Dat	-	112	This file contains only one record. It will have miscellaneous information like actual number of products, number of periods in a planning horizon, number of m/cs.

File Name	Key Field(s)	Rec. Size (bytes)	Remarks
Producti .Dat	Product Code	190	This file contains the forecasted depmand data and scheduled production level in each period over the planning horizon.
Machine .Dat	Machine Code	578	This file contains details of each machine, its capacity and performance parameters like efficiency, failure allowance.
Itemdata .Dat	Item** Code Foreign key: Product Code	2505	This file contains item data such as number of parents, parent codes (product structure), scheduled receipts, on-hand quantities (inventory status), lot sizing technique and item resource profile.
Bill.Dat	Product Code, Item Code, Machine Code	39	This file contains the output of bill of material processing that is number of units of each item that go in making an end item. This file is necessary for processing expert group technology module.
Resource .Dat	Product Code	22	This file contains the aggregate resource profile of an end item by exploding and summing the resources required by lower level items. This file will be generated by RRP module and is being used in both RRP and RCCP.
Group .Dat	Group Code	185	This fill will be generated by expert GT module to obtain the part machine cell and OPITZ to obtain part family.
Grpsetup .Dat	Group Code	16	This file is inputted after running expert-GT module or OPITZ module and it contains group setup time required by each part family on each of the work centres.

File Name	Key Field(s)	Rec. Size (bytes)	Remarks
Critical .Dat	Machine Code	101	This file contains the critical work centre details without using GT. It is generated by RCCP module.
Criticgt .Dat	Machine Code	101	It is similar to critical.dat but uses GT.
Reqrmnts .Dat	Item Code	2505	This file contains the gross requirements, net requirements, planned receipts, planned order releases in addition to itemdata.dat. It is generated by MRP module.
Grpseq .Dat	Group Code	91	This file contains the output information of group sequencing module such as group sequence, job sequence and group tardiness.

** Item Coding: The item code contains four characters. It is designed to identify each item uniquely and to incorporate low level coding. The first character represents the level of the item. The highest level item i.e. end item will have first character in its code as 'A', and that of next level as 'B' and so on. The next two characters identify the item uniquely among the items at the same level. The last character will be 'E' for end items, 'S' for subassemblies, and 'P' for purchase items.

5.4 PROGRAM FILES

The following programs have been coded in TURBO PASCAL version 4.0 which form building blocks to the integrated system developed on PC-XT/AT. The details are presented in the following table.

List of Program Files.

Sl. No.	Pascal File Name	Description	Memory Size	Main Procedure(s)	Calling Unit Names	Functions
1.	Global.Pas	Unit	5 K	None	None	Definition of all global variables including record structure and data files.
2.	Boxes.Pas	Unit	1.5 K	Box_1,Box_2 and errormessage	Crt (system Unit)	The procedure can draw single, double line windows and can exhibit error messages, when called.
3.	Database.Pas	Unit	21 K	Read_lotsize, Readitemdata, Create_database	Crt, global boxes	It can create production database, work centre database, and item database, when called.
4.	Editdata.Pas	Unit	47 K	Production_editor, Machine_editor, Itemdata_editor.	Crt, global, boxes and database	It offers editing facilities for production database, work centre database and item database.
5.	Bills.Pas	Unit	9 K	B_O_M	Crt, global, boxes	Evaluates bill of material from product structure.
6.	EXGT.Pas	Unit	42 K	Ex_GT	do	It forms TIJ, TI, CJ matrices and applies expert rules to form part families and machine cells.
7.	C_G_RRP.Pas	Unit	22 K	R_R_P	do	It evaluates the aggregate product resource families and calculates the number of resources required.
8.	C_G_RCCP.Pas	Unit	34 K	R_C_C_P	do	It evaluates critical work centres and adjusts the production level for each period.
9.	C_G_MRP.Pas	Unit	53 K	M_R_P	do	It calculates the material requirements for each item.
10.	C_G_CRP.Pas	Unit	12 K	C_R_P	do	It calculates the loading level on each work centres for executing MRP generated item requirements.
11.	GRPSCH.Pas	Unit	19 K	G_S	do	It calculates the group sequence and job sequence minimizing total tardiness.
12.	OPITZ.Pas	Unit	47 K	Module_Operator	do	It forms part families from the user description of item manufacturing and design attributes.
13.	MRPEXGT.Pas	Main Program	5 K	None	Crt,global,boxes, bills, EXGT, C_G_RRP, C_G_RCCP, C_G_MRP,C_G_CRP, GRPSCH, OPITZ	It is a main program and calls all main units.

5.5 IMPLEMENTATION FEATURES

The database is created by selecting database module option in the main menu (refer Chapter VI for details). The two options in the database module, create database and edit database can be used for creating and editing the database required for running the various modules implemented in the system. The details are presented in option numbers (1.1.1) and (1.1.2) in Chapter VI. The MRP-GT processing module ((1.2) of Chapter VI) option selected from main menu offers the options to run various modules viz. bill of material processing ((1.2.1) of Chapter VI), expert GT module ((1.2.2) of Chapter VI), resource requirement planning ((1.2.3) of Chapter VI), rough cut capacity planning ((1.2.4) of Chapter VI), material requirements planning ((1.2.5) of Chapter VI), capacity requirements planning ((1.2.6) of Chapter VI) and group sequencing ((1.2.7) of Chapter VI) modules.

The item data contained in the file itemdata.dat is processed to obtain the 'bill of material numbers'. The expert GT makes use of annual average demand of end items, bill of material data, work centre data to obtain TIJ, TI, CJ matrices. The [i,j]-th element of TIJ matrix represent quantity of time required in hours per average number of days in a bucket time on machine i by item j for meeting the total demand of item j required to produce the average bucket time demand of end items. TI matrix is a column matrix and the element in i-th row represent the available time in hours per average bucket-time on machine i. CJ is a row matrix and jth column element represent the production volume and item j in

units per average number of days in a bucket-time. These matrices are processed based on expert GT rules to obtain part family and machine cell combinations. The expert GT module also has an option to run it for a separately inputted TIJ, TI, CJ matrices data. After obtaining the groups, the group setup time data must be entered.

The RRP module evaluates the aggregate product resource families from the basic item resource data contained in itemdata.dat file and determines the number of work centres required to execute the production plan with and without the application of GT technique. Overload and underload work centres will also be exhibited for both cases. The available capacity can be altered, if desired. Finally the target production must be calculated by choosing appropriate option which gives perspective MPS for both cases. The perspective MPS depicts the advantages of applying GT technique.

The RCCP module evaluates the critical work centres and authorized MPS will be generated following the reduction by proportion or reduction by priority for products manufactured on critical work centres. The planning is carried out in each planning period over the planning horizon for both the cases viz. with and without GT. The authorized MPS for both the cases can be looked at critically and the advantage of applying GT will be easily sensed.

The authorized MPS, Itemdata.dat file forms the basic input to MRP. Bucket-wise demand will be calculated by following the 'work-day approach' mentioned earlier. MRP evaluates the gross, net requirements, planned order releases for each item and is carried out for both the cases.

The capacity requirements planning module evaluates the capacity requirements for executing the planned order releases of MRP. It is also carried out for both the cases and capacity plan for a work centre is graphically displayed over the number of MRP-buckets exploded.

The group sequencing module determines the group sequence and job sequence in the group minimizing total tardiness. The planned order releases of MRP and item lead times form the basic input at this stage. This module is also designed to run as a stand alone module by inputting data appropriately like expert GT module.

Though the different modules can be chosen randomly and run, it is left to the user's consciousness to run the options one after another sequentially from top to bottom as they appear in a menu. Also data integrity and prevention of false entries are given major importance in database creation. But it is upto the user to input the correctly coded items (following principles of item coding and low level coding), genuine product structure etc. for obtaining accurate results.

In the following chapter, we present a user's manual that is helpful while running the system.

5.6 INTERACTION OF DATA FILES WITH PROGRAMS

The Fig. 5.1 represents a schematic sketch of major data files inputted and outputted by various programs. By the term major data files we mean the files which will undergo major data processing while running the program. Actual.dat will be required by every program for reading one or two data elements.

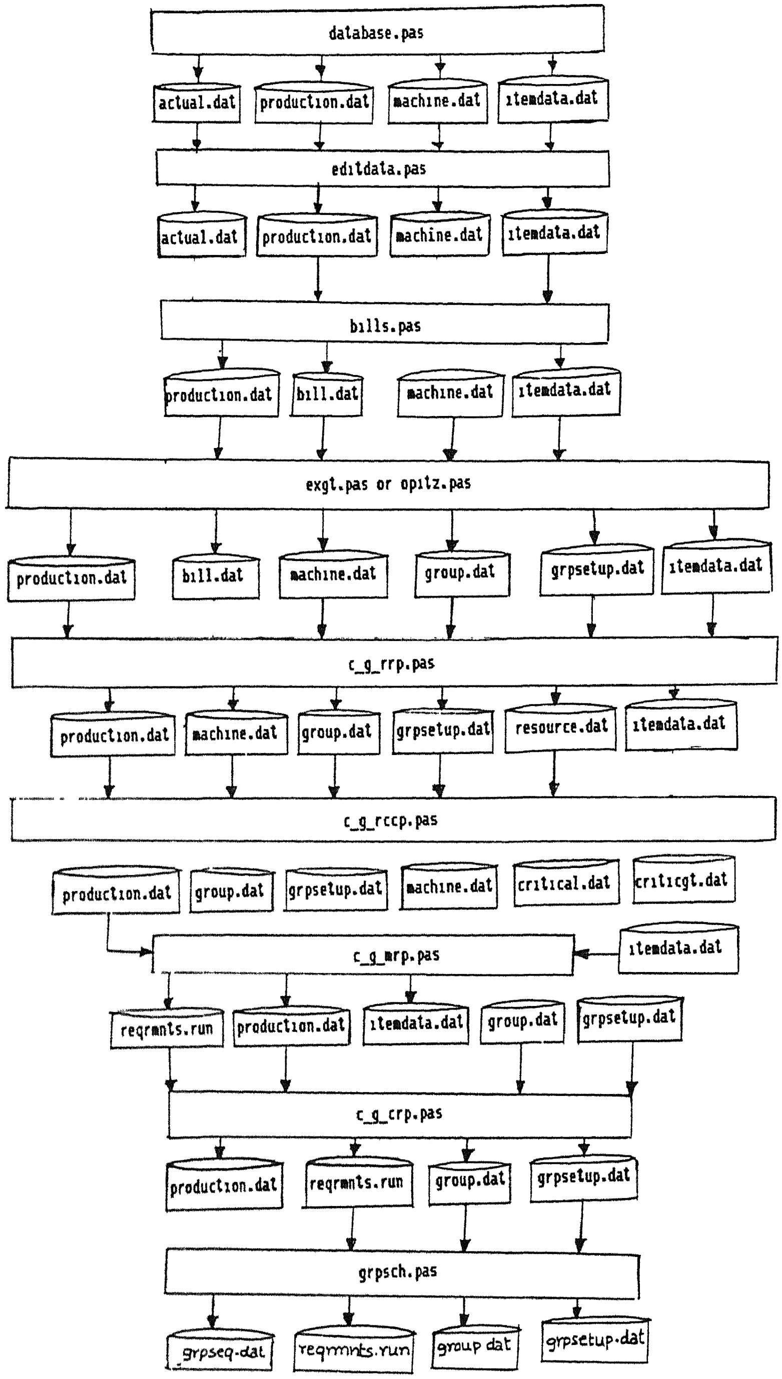


Fig. 5-1 : ..teraction of Program Files and Data Files.

CHAPTER VI

USER'S MANUAL

In this chapter, we provide a sequence of steps to be followed for effectively utilizing the system. Also we briefly mention the purpose of each option that appears in the menus which gives a preview of what happens when a particular option is run.

The operating menu (or main menu) has three options;

(1.0) 0. Exit to system

(1.1) 1. Database Module

(1.2) 2. MRP - GT Module

The second option of main menu (1.1) leads to Database module menu with three options to choose:

(1.1.1) 1. Create Database

(1.1.2) 2. Edit Database

(1.1.3) 3. Goto Previous menu

The first option of the database module (1.1.1) menu offers flexibility to create the following data files through the options.

(1.1.1.1) 1. Create factory calendar

(1.1.1.2) 2. Create demand database

(1.1.1.3) 3. Create work centre database

(1.1.1.4) 4. Create MRP-GT database

(1.1.1.5) 5. Go to previous menu

The first option of the create database module (1.1.1.1) enables to input the factory calendar, i.e. number of days in different periods, number of days in different buckets etc. The data inputted is stored in the file actual.dat.

The second option i.e. create demand database (1.1.1.2) seeks the forecasted demand schedules of each product for each period over the planning horizon. It is stored in Producti.dat.

The third option i.e. create work centre database (1.1.1.3) seeks the details of each work centre viz. its code, efficiency, failure allowance, number of machines, number of working hours per day and stores the details in Machine.dat file.

The fourth option i.e. create MRP-GT database (1.1.1.4) enables to create item, product structure, inventory status and resource profile data. This is stored in Itemdata.dat file.

The second option of database module i.e. edit database (1.1.2) gives the following editing options for each of the database module options viz. production database, work centre database and MRP-GT database.

(1.1.2.1) 1. Browse the records

(1.1.2.2) 2. Add a record

(1.1.2.3) 3. Modify a record

(1.1.2.4) 4. Delete a record

The above options are self-explanatory.

The second option of main menu i.e. MRP-GT processing module (1.2) gives the access to run the following modules:

(1.2.1) 1. Bill of material processing

(1.2.2) 2. Expert GT system

(1.2.3) 3. Resource requirement planning module

(1.2.4) 4. Rough cut capacity planning module

(1.2.5) 5. Material requirements planning module

(1.2.6) 6. Capacity requirement planning module

(1.2.7) 7. Group scheduling module

(1.2.8) 8. Go to previous menu

The bill of material processing module (1.2.1) generates bill of material i.e. number of lower level items that go into making an end item, from the product structure. It has an option to display the bills for specified product code. This module need not be repeated every time unless the product structure of an end item is altered.

The expert GT module (1.2.2) must be run after running bill of material processing module. It has the following options:

(1.2.2.1) 1. Run the system

(1.2.2.2) 2. Seek group setup times

(1.2.2.3) 3. List the PF-MCs (Groups)

(1.2.2.4) 4. Display the TIJ matrix

(1.2.2.5) 5. Display the TI matrix

(1.2.2.6) 6. Display the CJ matrix

(1.2.2.7) 7. Display the rejected item data

(1.2.2.8) 8. Quit the menu

The first option of expert GT module (1.2.2.1) forms the TIJ, TI, CJ matrices and forms groups by applying expert rules interactively on these matrices.

The second option (1.2.2.2) seeks the group setup times from the user. This option must be run before going to any other module.

The third (1.2.2.3), fourth (1.2.2.4), fifth (1.2.2.5) sixth (1.2.2.6) and seventh (1.2.2.7) options display the groups, TIJ matrix, TI matrix, CJ matrix and rejected item information, respectively.

The third option of MRP-GT processing module i.e. RRP module (1.2.3) would lead to the following options:

(1.2.3.1) 1. Run the RRP system

(1.2.3.2) 2. List overload work centres without grouping

(1.2.3.3) 3. List underload work centres without grouping

(1.2.3.4) 4. List overload work centres with grouping

(1.2.3.5) 5. List underload work centres with grouping

(1.2.3.6) 6. Change capacity of work centres

(1.2.3.7) 7. Calculate effective production level

(1.2.3.8) 8. See the effective production level

(1.2.3.9) 9. Go to previous menu

The first option (1.2.3.1) calculates the aggregate product resource families and determines the resources required to execute the production plan (inputted MPS) in the shopfloor.

The second, third, fourth, fifth options (1.2.3.2) - (1.2.3.5) determine respective work centres and displays them.

The sixth option (1.2.3.6) is run for changing the available shopfloor capacity, if any.

The seventh option (1.2.3.7) must be run before quitting the module. It evaluates the feasible production plan with the existing capacity. This output termed as 'Perspective MPS' will be fed to RCCP module.

The eighth option (1.2.3.8) displays the 'Perspective MPS' and advantage of applying GT technique can be easily seen.

The fourth option (1.2.4) of MRP-GT processing module runs the rough cut capacity planning system. That is it evaluates the critical work centres and the production is adjusted in each period by reducing the production by some proportion or by priority rule as the user chooses.

Finally the authorized MPS for each period with and without GT concept, will be displayed.

The fifth option of MRP-GT process (1.2.5) module i.e.,' MRP processing module' will display the following options;

(1.2.5.1) 1. Run without GT

(1.2.5.2) 2. Run with GT

(1.2.5.3) 3. Show results of option 1

(1.2.5.4) 4. Show results of option 2

(1.2.5.5) 5. Quit

First and second options (1.2.5.1, 1.2.5.2) runs the MRP processor with respective authorized MPS and displays the material plan for each item, in each case.

Third and fourth options (1.2.5.3, 1.2.5.4) enables to see the material plan of each item with and without GT.

Before this menu is displayed, the user is given an option to change the 'Authorized MPS' evaluated by RCCP module. This also serves the purpose of running MRP module with known 'Authorized MPS'.

The sixth option of MRP-GT processor, CRP module (1.2.6) will display the following choices:

(1.2.6.1) 1. Without GT

(1.2.6.2) 2. With GT

(1.2.6.3) 3. Quit

Each of the options first and second (1.2.6.1 and 1.2.6.2) gives user to choose the following options:

(1.2.6.1.1) 1. Run CRP system

(1.2.6.1.2) 2. Overload work centres

(1.2.6.1.3) 3. Show capacity plan

(1.2.6.1.4) 4. See histogram for a machine

(1.2.6.1.5) 5. Go to previous menu

The first option (1.2.6.1.1) runs the CRP system which evaluates the load profile of resources required for implementing the planned order releases of each item as generated by MRP system.

The second option (1.2.6.1.2) pin points the overload work centres. An overload work centre is a work centre whose availability is less than requirement in atleast one bucket time in the number of time buckets for which MRP is exploded.

The third option (1.2.6.1.3) displays the capacity plan of a work centre i.e. available number of hrs. vs. required no. of hrs. in each bucket for all the number of MRP time buckets explosion.

The fourth option (1.2.6.1.4) displays a graphical representation (a histogram) of the capacity plan.

The seventh option (1.2.7) of the MRP-GT processor, 'Group Scheduling' module will display the options:

(1.2.7.1) 1. Run the system

(1.2.7.2) 2. Shopfloor sequencing

(1.2.7.3) 3. Quit

The first option (1.2.7.1)runs the group scheduling algorithm and determines the group sequence as well as job sequence.

The second option (1.2.7.2) displays the sequencing to be implemented on the shopfloor.

The Fig. 6.1 is a schematic sketch of menu options.

PRECAUTIONS

1. There must be about 30K - 45K memory space on disk for writing the output files.

2. The item coding must follow the low level coding as discussed earlier.

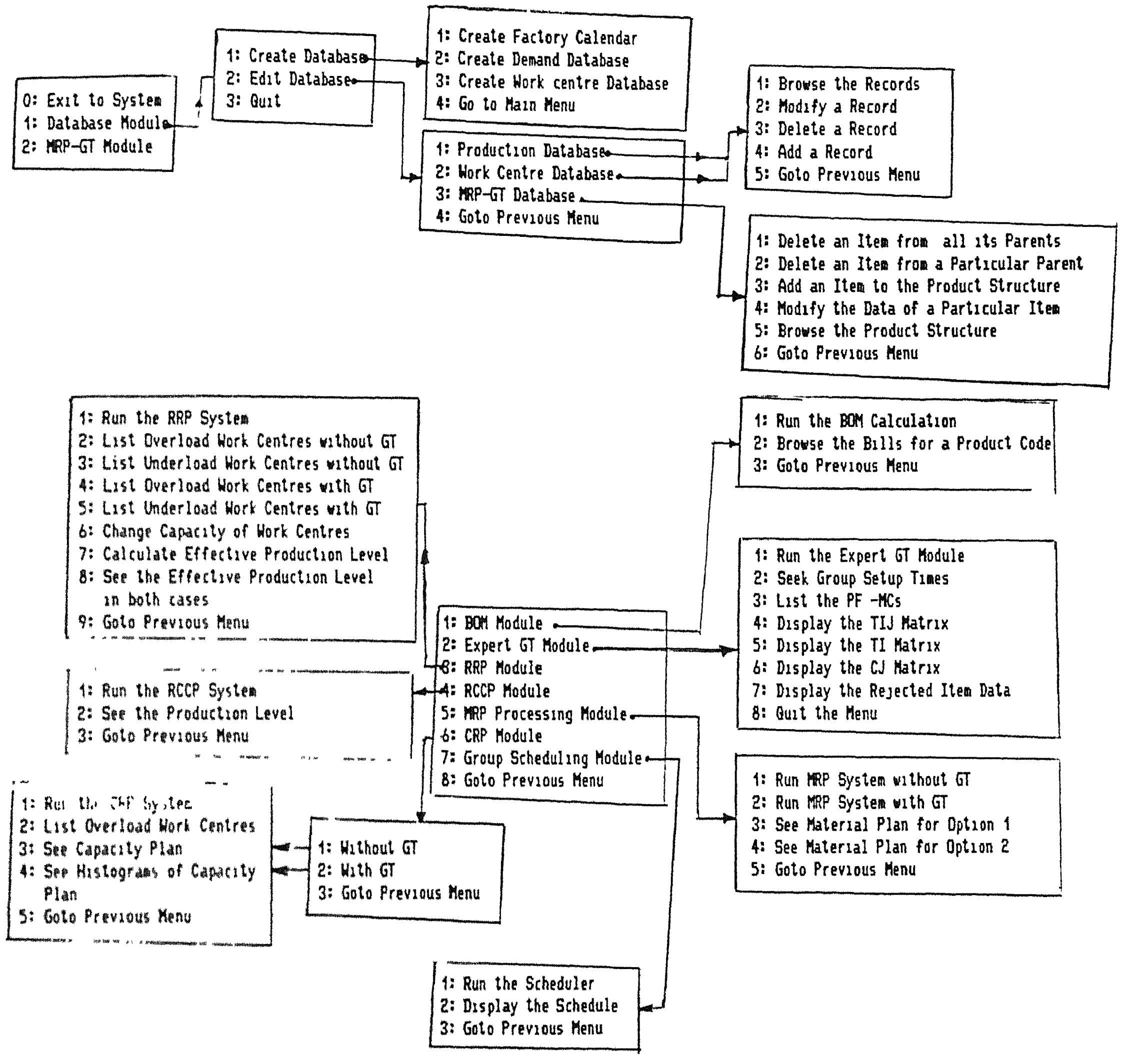


Fig. 6.1: Sketch of Menu Options.

CHAPTER VII

CONCLUSIONS AND SCOPE FOR FURTHER WORK

7.1 CONCLUSIONS

The present work has attempted in a novel concept of implementing a Material Requirements Planning (MRP) in a Computer Integrated Manufacturing Systems environment. The approach followed involves integration of Group Technology (GT) with MRP. Group Technology (GT) has become an indispensable tool with the evolution of Computer Integrated Manufacturing Systems (CIMS), intended to meet the ever changing consumer preferences by having a flexible production environment pertinent to batch type, multi-product situation. Group Technology is the realization that many production problems are similar and by combining different parts rationally, the problems can be made similar.

An expert system is incorporated to develop part families and machine cells following the GT concepts. The Master Production Schedule (MPS) inputted to MRP has been made feasible by Resource Requirements Planning, Rough Cut Capacity Planning (RCCP), and Capacity Requirements Planning (CRP) modules. A group scheduling algorithm is used to schedule i.e determining group

sequence and job sequence, the item requirements outputted by an MRP system. An integrated decision support system, built in TURBO PASCAL version 4.0, has been implemented on PC AT/XT. The system has been divided into number of PASCAL UNITS, which not only facilitates developing large programs exceeding 64K, but also reduces the compilation time required while developing the program.

7.2 SCOPE FOR FURTHER WORK

There are myriad problems in a production system. Because the present work focussed on a production planning problem in CIMS environment from scratch to finish, the various manufacturing problems which are not considered like man power scheduling, financial report generation capabilities, sequence dependent setup times, financial evaluation of alternate resources, budgeting, cash flow, etc. can be incorporated, in general.

To be specific, the production planning starts from aggregate production planning, which is based on demand forecast. So a suitable generalized methods for aggregate production planning and forecasting can be integrated to the present system. Also the low level coding of items is considered to have been done by the user. A methodology can be developed for building a low level coded items from a more user convenient input data.

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APPENDIX A

In this Appendix, we describe some of the commonly used methods for classifying parts into part families. As briefed in Chapter I, there are three various methods available for forming groups. They are visual inspection method, parts classification and coding system and clustering analysis.

The visual inspection method is the least commonly used and least expensive method. It is based on forming groups by looking at the parts or their photographs.

The parts classification and coding system, widely used in practice, arrives at part families by interactively seeking the various design/manufacturing parameters of the parts and bringing together the parts with similar attributes.

Many parts classification and coding systems have been developed throughout the world. They basically come under three general categories: (1) Systems based on part design attributes, (2) Systems based on part manufacturing attributes, (3) Systems based on both design and manufacturing attributes.

They can again be classified into three based on coding system structure: (1) Hierachial structure or Monocode, (2) Chain-type structure or Polycode, (3) Hybrid structure, a combination of hierachial and chain structure. With the hierachial structure, the interpretation of each succeeding symbol depends on the value of the preceding symbols. It provides a relatively compact structure which conveys much

information about the part in a limited number of digits.

In the chain type structure, the interpretation of each symbol in the sequence is fixed and does not depend on the values of preceding digits. The problem associated with this is that the code tends to be relatively long, on the other hand, the use of polycode allows for convenient identification of specific part attributes which will be of help in recognizing parts with similar processing requirements.

The hybrid structure is an attempt to achieve the best features of monocodes and polycodes by combining both the concepts. In a code, some digits will be independent as in polycode and other digits will be dependent on the preceding digits for their complete meaning as in monocode.

There are three parts classification and coding systems which are popular:

1) OPITZ 2) MICLASS 3) CODE

OPITZ classification system was developed by H. OPITZ [18] of the university of Aachen in West Germany. It represents one of the pioneering efforts in the group technology area and is perhaps the best known of the classification and coding schemes. It uses the following digit sequence:

12345 6789 ABCD

The basic code consists of nine digits, which can be extended by adding four more digits. The first nine digits are intended to convey both manufacturing and design attributes. The extra four digits, ABCD, are referred to as the 'Secondary code' and are intended to identify the production operation type and sequence.

The complete coding system is too complex to provide a comprehensive description here. Opitz wrote an entire book on his system [18]. However, to obtain a general idea of how OPITZ system works, let us examine the first five digits of the code, called form code which is intended to seek design attributes. The first digit identifies whether the part is rotational or a non-rotational part. It also describes the general shape and proportions of the part. Depending on first digit value, the second digit corresponds to relevant external shape and external shape elements like smoothness, threads, functional groove, stepping etc. The third digit corresponds to internal shape elements like internal holes, stepping, threads etc. Similarly digits 4 and 5 corresponds to various characteristics of plane surface machining and auxiliary holes, gear teeth respectively.

MICLASS and CODE systems are other popular classification and coding systems. The principles of coding by these systems are similar to that of OPITZ except the number of digits and the attributes of the digits are different in each of these systems. Each is tailor made to a particular type of industry and none can be said to be a best replacement over others. Though these systems are relatively in wide use, some of the inherent disadvantages with the use of these are:

(1) Enormous task and time consumption of coding all the company's parts involving lot of data handling.

(2) Non-availability of a system which is suitable to the generalized manufacturing industry.

(3) No specific relation to the shopfloor routing of the components.

The third method of group technology classification is by production flow analysis, which was originated by Burbidge [6]. It is a method of identifying part families and associated machine tool groupings by analyzing the production route sheets for parts produced in a given shop. It groups together the parts that have similar operation sequences and machine routings. Lot of research is done to cluster the parts having similar operations and machine routings. To solve the clustering problem, which is known to be NP-complete [Lawler, 19], many algorithms have been developed. Classification of clustering algorithms and some of the recent references published in the production and operations research literature are presented in Table I. Because the clustering problem is NP complete, heuristic algorithms are most likely to be used for solving large-scale

Table I

Type of clustering algorithm	Sample reference
Exchange algorithm	Mc cormack etal [20]., Bhat and Haupt [21]
Sorting algorithm	King [22],King and Nakornchai [23]
Constructive algorithm	Chandrasekharan and Rajagopalan [24]
Relaxation algorithm	Mulvey and Crowder [25]

industrial problems. A typical grouping problem may involve 200 machines (rows in matrix $[a_{ij}]$) and 2000 parts (columns in $[a_{ij}]$).

To illustrate the working of a clustering algorithm, consider the following machine_part incidence matrix $[a_{ij}]$,

$$[a_{ij}] = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{bmatrix} 1 & & & 1 \\ & & 1 & \\ 1 & & & 1 \\ & 1 & 1 & \end{bmatrix} \end{array} \text{Machine number}$$

Part number

$$\text{where } a_{ij} = \begin{cases} 1 & \text{if part } j \text{ is processed on machine } i \\ 0 & \text{otherwise} \end{cases}$$

By applying the clustering algorithm on the above matrix, one may obtain the following rearrangement of rows and columns.

$$
\begin{array}{cc|c}
 & & \begin{array}{cccc} \multicolumn{2}{c}{\text{PF-1}} & \multicolumn{2}{c}{\text{PF-2}} \\ 1 & 4 & 2 & 3 \end{array} \\
\text{MC-1} & \begin{array}{c} 1 \\ 3 \end{array} & \left[\begin{array}{cc|cc} 1 & 1 & & \\ 1 & 1 & & \\ \hline & & 1 & 1 \\ & & & 1 \end{array}\right] \\
\text{MC-2} & \begin{array}{c} 4 \\ 2 \end{array} &
\end{array}
$$

Part number

Two machine cells MC-1 ={1,3}, MC-2={4,2} and the corresponding part families PF-1 ={1,4} and PF-2 ={2,3} are clearly visible in the above matrix.

APPENDIX B

Design and Implementation of an Integrated
MRP-GT System for CIMS Environment

By
V.Ratna Kumar

Under the Guidance of
Dr. Kripa Shanker

Number of products	:	2
Number of work centers	:	7
Number of periods in the planning horzon	:	10
Number working days per annum	:	250
Number of time buckets for MRP explosion	:	10
Number of current period	:	1
Number of current bucket	:	1
Number of avg days in abucket	:	6
Number of avg. buckets in a period	:	5

Press any key to continue ......

Number of days in period 1 are 28
Number of days in period 2 are 25
Number of days in period 3 are 30
Number of days in period 4 are 26
Number of days in period 5 are 27
Number of days in period 6 are 28
Number of days in period 7 are 29
Number of days in period 8 are 26
Number of days in period 9 are 25
Number of days in period 10 are 26
Number of days in period 11 are 27
Number of days in period 12 are 28
Number of days in period 13 are 25
Number of days in period 14 are 28
Number of days in period 15 are 6

Number of days in bucket 1 are 7
Number of days in bucket 2 are 8
Number of days in bucket 3 are 5
Number of days in bucket 4 are 5
Number of days in bucket 5 are 5
Number of days in bucket 6 are 8
Number of days in bucket 7 are 5
Number of days in bucket 8 are 5
Number of days in bucket 9 are 5
Number of days in bucket 10 are 6
Number of days in bucket 11 are 6
Number of days in bucket 12 are 6
Number of days in bucket 13 are 6
Number of days in bucket 14 are 6
Number of days in bucket 15 are 6

Press any key to continue ......

Product Name :p1
Product Code :P1
Annual Demand :4000

Period	Demand
1	450
2	500
3	300
4	350
5	600
6	300
7	400
8	500
9	400
10	500

Quantity On Hand :20
Safety Stock :20

Press S to Stop Browsing, Otherwise any other Key to View Next Record

Product Name :p2
Product Code :P2
Annual Demand :4000

Period	Demand
1	400
2	500
3	400
4	500
5	300
6	400
7	500
8	400
9	500
10	600

Quantity On Hand :30
Safety Stock :30

Press S to Stop Browsing, Otherwise any other Key to View Next Record

Work Center :W1
Work Center Code :W1
Efficiency :0.95
Working Hours Per Day :8.00
Failure Allowance :1.10

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center :W2
Work Center Code :W2
Efficiency :0.90
Working Hours Per Day :8.00
Failure Allowance :1.40

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center :W3
Work Center Code :W3
Efficiency :0.90
Working Hours Per Day :8.00
Failure Allowance :1.03

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center :W4
Work Center Code :W4
Efficiency :0.95
Working Hours Per Day :8 00
Failure Allowance :1.10

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center	:w5
Work Center Code	:W5
Efficiency	:0.98
Working Hours Per Day	:8.00
Failure Allowance	:1.10

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center	:w6
Work Center Code	:W6
Efficiency	:0.90
Working Hours Per Day	:8.00
Failure Allowance	:1.10

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Work Center	:w7
Work Center Code	:W7
Efficiency	:0.94
Working Hours Per Day	:8.00
Failure Allowance	:1 20

Press S to Stop Browsing, Otherwise any other KEY to View Next Record

Product Code	:	P1
Item Code	:	ABCE

Total Setup Cost(Rs)	:	400.00
Inventory Cost/unit/bucket	:	4.00
Lead Time	:	2
Lot Size Technique	:	Wagner-Whitin Algorithm

Press any key to continue ....

```
 Resource Profile
 ----------------
Item Code            :ABCE
Work Center          :    W4
 Std. Time                      --->   : 5.00 mts
 Setup Time                     --->   : 9.00hrs


 Press S to Stop Browsing, Otherwise any other Key to View Next Record

Product Code       :     P2
Item Code          :     ABDE


Total Setup Cost(Rs)                 :     300.00
Inventory Cost/unit/bucket           :      3.00
Lead Time                            :     2
Lot Size Technique                   :     Lot for Lot
                         Press any key to continue ....


 Resource Profile
 ----------------
Item Code            :ABDE
Work Center          :    W5
 Std. Time                      --->   : 10.00 mts
 Setup Time                     --->   : 15.00hrs

WBrksEeStto Stop BrowsinW6 Otherwise any other Key to View Next Record
 Std. Time                      --->   : 10.00 mts
 Setup Time                     --->   : 15.00hrs

Product Code         :
Item Code            :     BCDS
Parents Code and Quantity Required    :


  ABDE  ->  3



                    Press any Key to Continue ....


Independent Demand:
------------------
Time Bucket No.1   :  40
Time Bucket No.2   :  20
Time Bucket No.3   :  30
Time Bucket No.4   :  40
Time Bucket No.5   :  30
Time Bucket No.6   :  40
Time Bucket No.7   :  30
Time Bucket No 8   :  40
Time Bucket No.9   :  30
Time Bucket No.10   :  30
```

```
Resource Profile
----------------
Item Code           :BCDS
Work Center         :    W4
 Std. Time                     --->   : 10.00 mts
 Setup Time                    --->   : 10.00hrs

Work Center         :    W7
 Std. Time                     --->   : 10.00 mts
 Setup Time                    --->   : 7.00hrs

Work Center         :    W6
 Std. Time                     --->   : 5.00 mts
 Setup Time                    --->   : 6.00hrs


Press S to Stop Browsing, Otherwise any other Key to View Next Record
```

```
Product Code         :
Item Code            :    BCES
Parents Code and Quantity Required    :


  ABCE  ->  2
  ABDE  ->  3


                Press any Key to Continue ....
```

```
Independent Demand:
------------------
Time Bucket No.1  :  40
Time Bucket No.2  :  30
Time Bucket No.3  :  40
Time Bucket No.4  :  50
Time Bucket No.5  :  20
Time Bucket No.6  :  30
Time Bucket No.7  :  40
Time Bucket No.8  :  30
Time Bucket No.9  :  40
Time Bucket No.10  :  40

Total Setup Cost(Rs)              :    100.00
Inventory Cost/unit/bucket        :     1.20
Lead Time                         :    2
Lot Size Technique                :    Wagner-Whitin Algorithm


                 Press any key to continue ....
```

```
 Resource Profile
 ----------------
 Item Code          :BCES
 Work Center        :     W2
  Std. Time                     --->   : 10.00 mts
  Setup Time                    --->   : 12 00hrs

 Work Center        :     W5
  Std. Time                     --->   · 15.00 mts
  Setup Time                    --->   : 18.00hrs

 Work Center        :     W6
  Std. Time                     --->   : 7.00 mts
  Setup Time                    --->   : 12.00hrs


  Press S to Stop Browsing, Otherwise any other Key to View Next Record


 Product Code        :
 Item Code           :    BCFS
 Parents Code and Quantity Required    :


   ABDE  ->  2

                  Press any Key to Continue ....


 Independent Demand:
 ------------------
 Time Bucket No.1   :  30
 Time Bucket No.2   :  30
 Time Bucket No.3   :  30
 Time Bucket No.4   :  30
 Time Bucket No.5   :  304
 Time Bucket No.6   :  40
 Time Bucket No.7   :  40
 Time Bucket No.8   :  40
 Time Bucket No.9   :  40
 Time Bucket No.10   :  40

 Total Setup Cost(Rs)               :    500.00
 Inventory Cost/unit/bucket         :     4.00
 Lead Time                          :    2
 Lot Size Technique                 :    Min. Order Quantity


                  Press any key to continue ....
```

```
Resource Profile
----------------
Item Code            :BCFS
Work Center          :    W3
 Std. Time                        --->   : 10.00 mts
 Setup Time                       --->   : 15.00hrs

Work Center          :    W2
 Std. Time                        --->   : 10.00 mts
 Setup Time                       --->   : 15.00hrs

Work Center          :    W5
 Std. Time                        --->   : 4.00 mts
 Setup Time                       --->   : 6.00hrs

Press S to Stop Browsing, Otherwise any other Key to View Next Record


Product Code         :
Item Code            :    BCGS
Parents Code and Quantity Required    :


  ABCE  ->  2

                   Press any Key to Continue ....


Independent Demand:
------------------
Time Bucket No.1  :  40
Time Bucket No.2  :  40
Time Bucket No.3  :  40
Time Bucket No.4  :  40
Time Bucket No.5  :  40
Time Bucket No.6  :  40
Time Bucket No.7  :  40
Time Bucket No.8  :  40
Time Bucket No.9  :  40
Time Bucket No.10  :  40

Total Setup Cost(Rs)            :    2000.00
Inventory Cost/unit/bucket      :    10.00
Lead Time                       :    2
Lot Size Technique              :    Modified EOQ

                   Press any key to continue ....
```

```
Resource Profile
----------------
Item Code          :BCGS
Work Center        :     W2
 Std. Time                      --->   : 20.00 mts
 Setup Time                     --->   : 10.00hrs

Work Center        :     W6
 Std. Time                      --->   : 20.00 mts
 Setup Time                     --->   : 20.00hrs

Work Center        :     W7
 Std. Time                      --->   : 10.00 mts
 Setup Time                     --->   : 7.00hrs
 Press S to Stop Browsing, Otherwise any other Key to View Next Record


Product Code       :
Item Code          :     CDEP
Parents Code and Quantity Required     :



  ABCE  ->  4
  ABDE  ->  3
  BCES  ->  2

                   Press any Key to Continue ....


Independent Demand:
------------------
Time Bucket No.1   :  30
Time Bucket No.2   :  40
Time Bucket No.3   :  50
Time Bucket No.4   :  60
Time Bucket No.5   :  0
Time Bucket No.6   :  0
Time Bucket No.7   :  0
Time Bucket No.8   :  0
Time Bucket No.9   :  0
Time Bucket No.10   :  0

Total Setup Cost(Rs)             :     100.00
Inventory Cost/unit/bucket       :      1.00
Lead Time                        :     1
Lot Size Technique               :     Least Total Cost

Product Code       :
Item Code          :     CDFP
Parents Code and Quantity Required    :
                   Press any key to continue ....


  BCDS  ->  2




                   Press any Key to Continue ....
```

```
Independent Demand:
------------------
Time Bucket No.1   :  40
Time Bucket No.2   :  50
Time Bucket No.3   :  50
Time Bucket No.4   :  50
Time Bucket No.5   :  0
Time Bucket No.6   :  0
Time Bucket No.7   :  0
Time Bucket No.8   :  0
Time Bucket No.9   :  0
Time Bucket No.10   :  0


Total Setup Cost(Rs)                 :     300 00
Inventory Cost/unit/bucket           :      5.00
Lead Time                            :     2
Lot Size Technique                   :     Min. Order Quantity


                         Press any key to continue ....

Product Code          :
Item Code             :     CDGS
Parents Code and Quantity Required     :



  BCGS  ->  3

                         Press any Key to Continue ....



Independent Demand:
------------------
Time Bucket No.1   :  0
Time Bucket No.2   :  0
Time Bucket No.3   :  0
Time Bucket No.4   :  0
Time Bucket No.5   :  0
Time Bucket No.6   :  0
Time Bucket No.7   :  0
Time Bucket No.8   :  0
Time Bucket No.9   :  0
Time Bucket No.10   :  0

Total Setup Cost(Rs)                 :     400.00
Inventory Cost/unit/bucket           :      3.00
Lead Time                            :     2
Lot Size Technique                   :     E O Q


                         Press any key to continue ....

 Resource Profile
 ----------------
Item Code             :CDGS
Work Center           :     W1
 Std. Time                        --->   : 4.00 mts
 Setup Time                       --->   : 5.00hrs

Work Center           :     W5
 Std. Time                        --->   : 5.00 mts
 Setup Time                       --->   : 6.00hrs


 Press S to Stop Browsing, Otherwise any other Key to View Next Record
```

```
Product Code        :
Item Code           :    CDHP
Parents Code and Quantity Required    :



  BCGS  ->  2
  BCFS  ->  1

                  Press any Key to Continue ....



Independent Demand.
-----------------
Time Bucket No.1  :  10
Time Bucket No.2  :  20
Time Bucket No.3  :  40
Time Bucket No.4  :  50
Time Bucket No.5  :  60
Time Bucket No.6  :  40
Time Bucket No.7  :  30
Time Bucket No.8  :  40
Time Bucket No.9  :  40
Time Bucket No.10  :  30

Total Setup Cost(Rs)              :    200.00
Inventory Cost/unit/bucket        :     1.30
Lead Time                         :    3
Lot Size Technique                :    Least Unit Cost

                  Press any key to continue ....

Product Code        :
Item Code           :    DEFP
Parents Code and Quantity Required    :
                    :


  CDGS  ->  5

                  Press any Key to Continue ....



Independent Demand:
-----------------
Time Bucket No.1  :  0
Time Bucket No.2  :  0
Time Bucket No.3  :  0
Time Bucket No.4  :  0
Time Bucket No.5  :  0
Time Bucket No.6  :  0
Time Bucket No.7  :  0
Time Bucket No.8  :  0
Time Bucket No.9  :  0
Time Bucket No.10  :  0


Total Setup Cost(Rs)              :    300.00
Inventory Cost/unit/bucket        :     7.00
Lead Time                         :    2
Lot Size Technique                :    Modified LTC


                  Press any key to continue ....
```

```
MRP-GT PROCESSING MENU

1: Bill of Material Module
2: Expert GT Module
3: Resource Requirement Planning Module
4: Rough Cut Capacity Planning Module
5: MRP Processing Module
6: Capacity Requirement Planning Module
7: Group Scheduling Module
8: Go To Previous Menu

Input Choice :
```

```
BILL SYSTEM

1) Run the BOM Calculation
2) Browse the Bills for a Product Code
3) Go to Previous Menu

Type Your Choice     :1
```

```
Input the Product Code (for which BOM is to be Browsed)  :p1
```

```
Product Code                    :P1

Item Code                       :ABCE

Quantity                        :1

Machine_code                    :W4

Standard time/product (mts) :   5.00

Set Up Time (hrs)           :   9 00


     Press S to Stop or any other key to view next Record.....
Product Code                    :P1

Item Code                       :BCGS

Quantity                        :2

Machine_code                    :W2

Standard time/product (mts) :  40.00

Set Up Time (hrs)           :  10.00


     Press S to Stop or any other key to view next Record ....
```

```
Product Code                    :P1
Item Code                       :CDEP
Quantity                        :4
Machine_code                    :PURC
Standard time/product (mts) :  0.00
Set Up Time (hrs)           :  0.00

     Press S to Stop or any other key to view next Record.....

Product Code                    :P1
Item Code                       :CDGS
Quantity                        :6
Machine_code                    :W1
Standard time/product (mts) : 24.00
Set Up Time (hrs)           :  5.00

     Press S to Stop or any other key to view next Record.....

Product Code                    :P1
Item Code                       :DEFP
Quantity                        :30
Machine_code                    :PURC
Standard time/product (mts) :  0.00
Set Up Time (hrs)           :  0.00

 EXPERT GROUP TECHNOLOGY MENU other key to view next Record.....

   1 : Run the Expert GT Module
   2 : Seek Group Set Up Times
   3 : List The PF-MCs ( Groups )
   4 : Display the TIJ Matrix
   5 : Display the TI  Matrix
   6 : Display the CJ  Matrix
   7 : Display Rejected Item Data
   8 : Quit the Menu

      Input  Option :1
```

This module can be run with the data entered along with the other modules or it can be run as stand alone module by entering the required data. However, Please note that groups formed by running as a seperate stand alone module can not be used with other modules.

Would You Wish to Run as a Stand Alone Module ? (Y/N) :n

Input the Max. Machine Length on the Shopfloor :20

Minimum Possible Shop Length W/o any Constraints is 8

Is (Are) there any Sequence Constraint(s)?(Y/N) :y

Enter Number of Sequence Constraints : 2

Enter number of Machines in Constraint 1 :2

Enter number of Machines in Constraint 1 :2

Enter Machine 1 in constraint 1 :w1
Enter Machine 2 in constraint 1 .w6

```
Enter number of Machines in Constraint    2  :2

Enter  Machine     1 in constraint 2     :w4
Enter  Machine     2 in constraint 2     :w5


                   Constraint 2



                   Press any key
The following is the Old Process Plan for the Item


Machine - Code Standard Time/Item (mts.)


     W5                    5.9391
     W1                    4.7208

Enter the process plan without using machine     W1.

                   No. of Machines in the New Process Plan :2


                   Enter Machine Code of Machine    1 : w3

                   Input Standard Time/Item (mts.)  : 2

The following is the Old Process Plan for the Item


Machine - Code Standard Time/Item (mts.)


     W5                    5.9391
     W1                    4.7208

Enter the process plan without using machine     W1.

                   No. of Machines in the New Process Plan :2


                   Enter Machine Code of Machine    2 : w5

                   Input Standard Time/Item (mts.)  : 9

                   Constraint 2


                   Press any key


The following are the machines required by items BCGS :


     W6       W2       W7


Is there any alternate process plan for the item without using   W7 ? (Y/N) :n
```

The following are the machines required by items BCDS :

U6 U7 U4

Is there any alternate process plan for the item without using U7 ? (Y/N) :n

Constraint 1

Press any key

Possible PF_MC Combination Number 3

Machine Code	Item Code	ST W/o GT
U3	BCFS	15

Individual Set Up Time of Items Machined on the Machine U3
are shown in third column ....

The Setup time shown is average requirement per Bucket-time (in Hrs.) ....

Please Input Group Set Up Time for the PF on the Machine :

Possible PF_MC Combination Number 3

Machine Code	Item Code	ST W/o GT
U3	BCFS	15

Individual Set Up Time of Items Machined on the Machine U3
are shown in third column ....

The Setup time shown is average requirement per Bucket-time (in Hrs.) ....

Please Input Group Set Up Time for the PF on the Machine : 14

The following are the Items Machined on the Machine U3 :

BCFS

Is there any Alternate Process Plan
for any of the Items Machined on U3 (Y/N) :n

Using Knapsack algorithm.   Please wait

Part Family, Machine Cell Combination Number 1
==

Machine Cell	Part Family
U5	CDGS
U2	
U4	

Press Any Key to Continue ......

Part Family, Machine Cell Combination Number 2
==

Machine Cell	Part Family
U6	BCES
U1	BCGS
	ABDE
	BCDS

Press Any Key to Continue ......

Part Family, Machine Cell Combination Number 3
==

Machine Cell	Part Family
U3	BCFS

Press Any Key to Continue ......

Rejected items which are to be Manufactured in Functional Layout are ...
==

Item Code	Machine Code	Time/Bucket(hrs)
BCGS	U2	54
BCGS	U6	64
BCGS	U7	29
BCDS	U4	43
BCDS	U6	22
BCDS	U7	40
BCFS	U3	37

Press Any Key to Continue ....

	ABCE	BCES	BCGS	CDGS	ABDE	BCDS	BCFS
U4	14	0	0	0	0	43	0
U2	0	67	54	0	0	0	37
U5	0	100	0	39	26	0	15
U6	0	50	64	0	26	22	0
U7	0	0	29	0	0	40	0
U1	0	0	0	31	0	0	0
U3	0	0	0	0	0	0	37

No. of Items : 7 No. of Machines : 7

Press Any Key to Continue ....

Machine Code	Time/Bucket (Hrs)
U4	66
U2	263
U5	197
U6	197
U7	99
U1	66
U3	33

Press Any Key to Continue ......

Item Code	Volume/Bucket (Units)
ABCE	66
BCES	328
BCGS	131
CDGS	394
ABDE	66
BCDS	197
BCFS	131

Press Any Key to Continue ......

```
EXPERT GROUP TECHNOLOGY MENU

1 : Run the Expert GT Module
2 : Seek Group Set Up Times
3 : List The PF-MCs ( Groups )
4 : Display the TIJ Matrix
5 : Display the TI  Matrix
6 : Display the CJ  Matrix
7 : Display Rejected Item Data
8 : Quit the Menu

Input  Option :1
```

This module can be run with the data entered along with the other modules or it can be run as stand alone module by entering the required data. However, Please note that groups formed by running as a seperate stand alone module can not be used with other modules.

```
Would You Wish to Run  as a Stand Alone Module ? (Y/N) :n

Input the Max. Machine Length on the Shopfloor  :30
Minimum Possible Shop Length W/o any Constraints is    8

Enter number of Machines in Constraint    1  :2

Enter  Machine    1 in constraint 1    :w1
Enter  Machine    2 in constraint 1    :w2

Enter number of Machines in Constraint    2  :2

Enter  Machine    1 in constraint 2    :w4
Enter  Machine    2 in constraint 2    :w5

Enter number of Machines in Constraint    3  :2

Enter  Machine    1 in constraint 3    :w6
Enter  Machine    2 in constraint 3    :w7
```

```
Possible PF_MC Combination Number  1

Machine Code  Item Code   ST W/o GT

     W1          CDGS
     W2          BCES
     W5          BCGS
     W6          BCFS         15
     W7          ABDE
     W3          BCDS
Individual Set Up Time  of Items Machined on the Machine   W3
            are shown in third column .......

The Setup time shown is average requirement per Bucket-time (in Hrs.) ....

Please Input Group Set Up Time for the PF on the Machine : 10


Part Family, Machine Cell Combination Number 1
===============================================

      Machine Cell              Part Family
      ------------              -----------

       W1                        CDGS
       W2                        BCES
       W5                        BCGS
       W6                        BCFS
       W7                        ABDE
       W3                        BCDS
       W4                        ABCE


          Press Any Key to Continue ......

                    The Part Family Combination
                    ==========================

                          CDGS
                          BCES
                          BCGS
                          BCFS
                          ABDE
                          BCDS
                          ABCE


The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine W1 is :5
Enter The Group Set Up Time for the Part Family on the Machine  W1:5
```

The Part Family Combination
=========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine W2 is :37
Enter The Group Set Up Time for the Part Family on the Machine W2:20

The Part Family Combination
=========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine W5 is :45
Enter The Group Set Up Time for the Part Family on the Machine W5:30

The Part Family Combination
=========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine W6 is :53
Enter The Group Set Up Time for the Part Family on the Machine W6:30

The Part Family Combination
=========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine W7 is :14
Enter The Group Set Up Time for the Part Family on the Machine W7:10

The Part Family Combination
==========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine U3 is :15
Enter The Group Set Up Time for the Part Family on the Machine U3:10

The Part Family Combination
==========================

CDGS
BCES
BCGS
BCFS
ABDE
BCDS
ABCE

The Set Up times given below are Average Hrs./Bucket

Individual Set Up Time on the Machine U4 is :19
Enter The Group Set Up Time for the Part Family on the Machine U4:13

MRP-GT PROCESSING MENU
1: Bill of Material Module 2: Expert GT Module 3: Resource Requirement Planning Module 4: Rough Cut Capacity Planning Module 5: MRP Processing Module 6: Capacity Requirement Planning Module 7: Group Scheduling Module 8: Go To Previous Menu
Input Choice :3

Input Shop Load Factor :0.9

Over Load Work Centres without grouping (GT)

Work Centre	Number of Machines Available	Required
W2	8	10
W3	1	2
W4	2	3
W5	6	8
W6	6	8
W7	3	4

Press any key to continue ...

Over Load Work Centres with Grouping (GT)

Work Centre	Number of Machines Available	Required
W3	1	2
W4	2	3
W5	6	7

Press any key to continue ...

Effective Production Level With the Present Capacity

Product-Code	Without GT	With GT
P1	263	325
P2	275	340

Press any Key to Continue ....

MRP-GT PROCESSING MENU

1: Bill of Material Module
2: Expert GT Module
3: Resource Requirement Planning Module
4: Rough Cut Capacity Planning Module
5: MRP Processing Module
6: Capacity Requirement Planning Module
7: Group Scheduling Module
8: Go To Previous Menu

Input Choice :4

This Module takes the Perspective Production level arrived by the Re_ source Requiremnt Module to show the Critical Work Centers. However here is an option incorporated to change the target production level. This serves the dual purpose of running the module without RRP also.

Would You Wish to Change the Production Data ? (Y/N) :n

Input Shop Load Factor :0.9

Following is the Code and Utilisation Ratio of Critical Machines

W/o, W/, B under VARIABLE column indicates
With GT, Without GT and in Both Cases respectively

Machine Code	W/o	W/	VARIABLE
W2	1.31	1.13	B
W3	1.57	1.39	B
W4	1.29	1.18	B
W5	1.45	1.28	B
W6	1.55	1.1[illegible]	B
W7	1.21	1.15	B

Press any Key to Continue

Without GT
==========

In Period 1
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.83 Of Requested Production

Product Code	Demand In Period 1
P1	450
P2	400

Press any Key to continue...

Without GT
==========

In Period 2
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.55 Of Requested Production
Product Code   Demand In Period 2

P1	500
P2	500

Press any Key to continue...

Without GT
==========

Period 3

P1	300
P2	400

Press any Key to continue...

Without GT
==========

In Period 4
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.59 Of Requested Production
Product Code   Demand In Period 4

P1	350
P2	500

Press any Key to continue...

Without GT
==========

In Period 5
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.83 Of Requested Production
Product Code   Demand In Period 5

P1	600
P2	300

Press any Key to continue...

In Period 6
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.83 Of Requested Production
Product Code Demand In Period 6

P1	300
P2	400

Press any Key to continue...

With GT
=======

In Period 1
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.99 Of Requested Production
Product Code Demand In Period 1

P1	450
P2	400

Press any Key to Continue...

With GT
=======

In Period 2
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.68 Of Requested Production
Product Code Demand In Period 2

P1	500
P2	500

Press any Key to Continue...

With GT
=======

In Period 3
Production Capacity is Greater than requesred Production Level

Critical Capacity is 1.09 of requested production

Press any Key to continue... :

With GT
=======

In Period 4
Production Capacity Is Less Than Requested Production Level
Critical Capacity Is Only 0.72 Of Requested Production
Product Code Demand In Period 4

P1	325
P2	500

Press any Key to Continue...

With GT
=======

In Period 5
Production Capacity Is Less Than Requested Production Level

Critical Capacity Is Only 0.95 Of Requested Production

Product Code	Demand In Period 5
P1	600
P2	340

Press any Key to Continue...

With GT
=======
In Period 6
Production Capacity is Greater than requesred Production Level

Critical Capacity is 1.10 of requested production

Press any Key to continue... :
P,S,N under Criterion Column indicates Priority, Proportion, Not Critical

Period Number 1
===============

Product Code	With GT	Criterion	Without GT	Criterion
P1	447	S	373	S
P2	397	S	331	S

Press Any Key To Continue ...

P,S,N under Criterion Column indicates Priority, Proportion, Not Critical

Period Number 3
===============

Product Code	With GT	Criterion	Without GT	Criterion
P1	325	N	277	S
P2	400	N	369	S

Press Any Key To Continue ...

P,S,N under Criterion Column indicates Priority, Proportion, Not Critical

Period Number 6

Product Code	With GT	Criterion	Without GT	Criterion
P1	325	N	248	S
P2	360	N	331	S

Press Any Key To Continue ...

P,S,N under Criterion Column indicates Priority, Proportion, Not Critical

Period Number 9

Product Code	With GT	Criterion	Without GT	Criterion
P1	272	S	220	S
P2	340	S	275	S

Press Any Key To Continue ...

This Module takes the Authorized Production level arrived by RCCP Module to generate Material Requirements. However here is an option available to alter the Perspective Production level in each period. This serves the dual purpose of running the module without RCCP also.

Would You Wish to Change the Production Data ? (Y/N) :n

MRP PROCESSOR

1: Run MRP System Without GT
2: Run MRP System With GT
3: See Material Plan for option 1
4: See Material Plan for option 2
5: Go To Main Menu

Type Your Choice :1

Lot size : Wagner - Whitin Algorithm
Lead time : 2
Safety stock : 20
On hand : 20
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	93	106	66	66	61	88	55	55	53	55
Sch. Rec.	0	0	0	0	0	0	0	0	0	0
Net Req.	93	106	66	66	61	88	55	55	53	55
Proj on hd	392	286	220	154	93	203	148	93	148	93
Plan Rec.	485	0	0	0	0	198	0	0	108	0
Plan Relses	0	0	0	198	0	0	108	0	0	0

Orders to be Expedited :
An order of 485 to be released in period -2 for requirement in Bucket 1

Press any key to Continue (See next item) ...

Item code : BCDS
Lot size : Fixed Period Requirements
Lead time : 2
Safety stock : 50
On hand : 40
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	217	197	201	304	195	205	198	259	30	30
Sch. Rec.	50	50	0	0	0	0	0	0	0	0
Net Req.	177	147	201	304	195	205	198	259	30	30
Proj on hd	0	0	304	0	205	0	259	0	30	0
Plan Rec.	177	147	505	0	400	0	457	0	60	0
Plan Relses	505	0	400	0	457	0	60	0	0	0

Orders to be Expedited :
An order of 177 to be released in period -2 for requirement in Bucket 1
An order of 147 to be released in period -1 for requirement in Bucket 2

Press any key to Continue (See next item) ...

Item code : BCFS
Lot size : Min. Order Quantity
Lead time : 2
Safety stock : 40
On hand : 30
Allocated : 10

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	148	148	144	206	414	150	152	186	40	40
Sch. Rec.	90	100	0	0	0	0	0	0	0	0
Net Req.	78	48	144	206	414	150	152	186	40	40
Proj on hd	0	0	58	54	0	52	102	118	78	38
Plan Rec.	78	48	202	202	360	202	202	202	0	0
Plan Relses	202	202	360	202	202	202	0	0	0	0

Orders to be Expedited :
An order of 78 to be released in period -2 for requirement in Bucket 1
An order of 48 to be released in period -1 for requirement in Bucket 2

Press any key to Continue (See next item) ...

Item code : CDEP
Lot size : Least Total Cost
Lead time : 1
Safety stock : 100
On hand : 40
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	207	1637	2327	1116	165	165	680	299	0	0
Sch. Rec.	50	50	40	45	45	56	40	50	50	40
Net Req.	217	1587	2287	1071	120	109	640	249	0	0
Proj on hd	0	0	0	120	0	0	0	0	50	90
Plan Rec.	217	1587	2287	1191	0	109	640	249	0	0
Plan Relses	1587	2287	1191	0	109	640	249	0	0	0

Orders to be Expedited :
An order of 217 to be released in period -1 for requirement in Bucket 1

Press any key to Continue (See next item) ...

Item code : CDGS
Lot size : E O Q
Lead time : 2
Safety stock : 30
On hand : 50
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	0	1188	240	0	768	360	0	0	0	0
Sch. Rec.	20	80	0	0	0	0	0	0	0	0
Net Req.	0	1068	240	0	768	360	0	0	0	0
Proj on hd	40	0	21	21	0	0	0	0	0	0
Plan Rec.	0	1068	261	0	747	360	0	0	0	0
Plan Relses	261	0	747	360	0	0	0	0	0	0

Orders to be Expedited :
An order of 1068 to be released in period -1 for requirement in Bucket 2

Press any key to Continue (See next item) ...

Item code : CDHP
Lot size : Least Unit Cost
Lead time : 3
Safety stock : 30
On hand : 0
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	212	1014	560	252	774	482	30	40	40	30
Sch. Rec.	30	50	80	0	0	0	0	0	0	0
Net Req.	212	964	480	252	774	482	30	40	40	30
Proj on hd	0	0	0	0	0	0	80	40	0	0
Plan Rec.	212	964	480	252	774	482	110	0	0	30
Plan Relses	252	774	482	110	0	0	30	0	0	0

Orders to be Expedited :
An order of 212 to be released in period -3 for requirement in Bucket 1
An order of 964 to be released in period -2 for requirement in Bucket 2
An order of 480 to be released in period -1 for requirement in Bucket 3
Press any key to Continue (See next item) ...

MRP PROCESSOR

1: Run MRP System Without GT
2: Run MRP System With GT
3: See Material Plan for option 1
4: See Material Plan for option 2
5: Go To Main Menu

Type Your Choice :2

Item code : ABDE
Lot size : Lot for Lot
Lead time : 2
Safety stock : 30
On hand : 30
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	99	113	70	70	69	108	67	67	67	79
Sch. Rec.	0	0	0	0	0	0	0	0	0	0
Net Req.	99	113	70	70	69	108	67	67	67	79
Proj on hd	0	0	0	0	0	0	0	0	0	0
Plan Rec.	99	113	70	70	69	108	67	67	67	79
Plan Relses	70	70	69	108	67	67	67	79	0	0

Orders to be Expedited :
An order of 99 to be released in period -2 for requirement in Bucket 1
An order of 113 to be released in period -1 for requirement in Bucket 2

Press any key to Continue (See next item) ...

Item code : BCDS
Lot size : Fixed Period Requirements
Lead time : 2
Safety stock : 50
On hand : 40
Allocated : 0

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	250	230	237	364	231	241	231	277	30	30
Sch. Rec.	50	50	0	0	0	0	0	0	0	0
Net Req.	210	180	237	364	231	241	231	277	30	30
Proj on hd	0	0	364	0	241	0	277	0	30	0
Plan Rec.	210	180	601	0	472	0	508	0	60	0
Plan Relses	601	0	472	0	508	0	60	0	0	0

Orders to be Expedited :
An order of 210 to be released in period -2 for requirement in Bucket 1
An order of 180 to be released in period -1 for requirement in Bucket 2

Press any key to Continue (See next item) ..

```
Lot size            : Min. Order Quantity
Lead time           :  2
Safety stock        :  40
On hand             :  30
Allocated           :  10
```

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	170	170	168	246	438	174	174	198	40	40
Sch. Rec.	90	100	0	0	0	0	0	0	0	0
Net Req.	100	70	168	246	438	174	174	198	40	40
Proj on hd	0	0	45	12	0	39	78	93	53	13
Plan Rec.	100	70	213	213	426	213	213	213	0	0
Plan Relses	213	213	426	213	213	213	0	0	0	0

```
        Orders to be Expedited :
An order of  100 to be released in period  -2  for requirement in Bucket 1
An order of   70 to be released in period  -1  for requirement in Bucket 2

            Press any key to Continue (See next item) ...
```

```
Item code           : CDFP
Lot size            : Min. Order Quantity
Lead time           :  2
Safety stock        :  40
On hand             :  40
Allocated           :   0
```

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	1242	50	994	50	1016	0	120	0	0	0
Sch. Rec.	60	40	50	0	0	0	0	0	0	0
Net Req.	1182	10	944	50	1016	0	120	0	0	0
Proj on hd	0	0	0	154	0	0	84	84	84	84
Plan Rec.	1182	10	944	204	862	0	204	0	0	0
Plan Relses	944	204	862	0	204	0	0	0	0	0

```
        Orders to be Expedited :
An order of 1182 to be released in period  -2  for requirement in Bucket 1
An order of   10 to be released in period  -1  for requirement in Bucket 2

            Press any key to Continue (See next item) ...
```

```
Item code           : CDHP
Lot size            : Least Unit Cost
Lead time           :  3
Safety stock        :  30
On hand             :   0
Allocated           :   0
```

Bucket	1	2	3	4	5	6	7	8	9	10
Gross Req.	223	1201	962	263	273	669	30	120	40	30
Sch Rec.	30	50	80	0	0	0	0	0	0	0
Net Req.	223	1151	882	263	273	669	30	120	40	30
Proj on hd	0	0	0	0	0	0	120	0	30	0
Plan Rec.	223	1151	882	263	273	669	150	0	70	0
Plan Relses	263	273	669	150	0	70	0	0	0	0

```
        Orders to be Expedited :
An order of  223 to be released in period  -3  for requirement in Bucket 1
An order of 1151 to be released in period  -2  for requirement in Bucket 2
An order of  882 to be released in period  -1  for requirement in Bucket 3
            Press any key to Continue (See next item) ...
```

MRP-GT PROCESSING MENU

1: Bill of Material Module
2: Expert GT Module
3: Resource Requirement Planning Module
4: Rough Cut Capacity Planning Module
5: MRP Processing Module
6: Capacity Requirement Planning Module
7: Group Scheduling Module
8: Go To Previous Menu

Input Choice :6

1 : without GT

2 : with GT

3: Quit

Type Your Choice :1

CRP PROCESS MENU

1: Run the CRP System
2: List Over Load Work Centres
3: See Capacity Plan
4: See Histograms Of Capacity Plan
5: Go To Previous Menu

Type Your Choice :1

Input Shop Load Factor :0.9

Over Load Work Centres

Work Centres Code :

W2
W3
W4
W5
W6
W7

Work Centre : W3
Press any key to Continue ...

CAPACITY PLAN

Bucket	Available Machine hours	Required Machine hours	Difference Machine hours
1	56.00	48.67	7.33
2	64.00	48.67	15.33
3	40.00	75.00	-35.00
4	40.00	48.67	-8.67
5	40.00	48.67	-8.67
6	64.00	48.67	15.33
7	40.00	0.00	40.00
8	40.00	0.00	40.00
9	40.00	0.00	40.00
10	48.00	0.00	48.00

Press S to Stop Browsing otherwise any other KEY to Get Next Record

Work Centre : W3

CAPACITY PLAN

Bucket	Available Machine hours	Required Machine hours	Difference Machine hours
1	56.00	48.67	7.33
2	64.00	48.67	15.33
3	40.00	75.00	-35.00
4	40.00	48.67	-8.67
5	40.00	48.67	-8.67
6	64.00	48.67	15.33
7	40.00	0.00	40.00
8	40.00	0.00	40.00
9	40.00	0.00	40.00
10	48.00	0.00	48.00

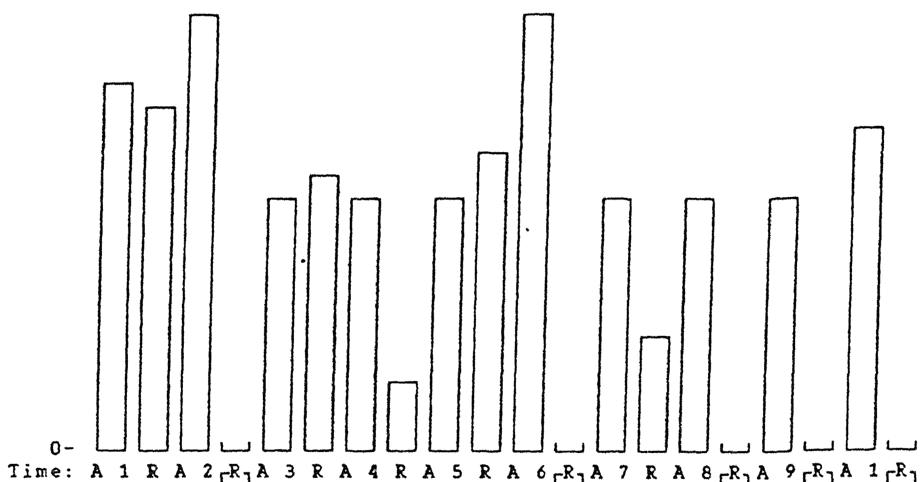
Press S to Stop Browsing otherwise any other KEY to Get Next Record

Work Centre : W6

CAPACITY PLAN

Bucket	Available Machine hours	Required Machine hours	Difference Machine hours
1	336.00	72.92	263.08
2	384.00	271.67	112.33
3	240.00	245.35	-5.35
4	240.00	29.67	210.33
5	240.00	173.58	66.42
6	384.00	84.17	299.83
7	240.00	52.00	188.00
8	240.00	43.83	196.17
9	240.00	0.00	240.00
10	288.00	0.00	288.00

Press S to Stop Browsing otherwise any other KEY to Get Next Record



Work Centre :W4 Press any key to continue....

CRP PROCESS MENU

1: Without GT
2: With GT
3: Quit

Type Your Choice :2

Input Shop Load Factor .0.9

Over Load Work Centres

Work Centres Code :

W2
W3
W4
W5
W6
W7

Press any key to Continue ...

Work Centre : W3

CAPACITY PLAN

Bucket	Available Machine hours	Required Machine hours	Difference Machine hours
1	56.00	45.50	10.50
2	64.00	45.50	18.50
3	40.00	81.00	-41.00
4	40.00	45.50	-5.50
5	40.00	45.50	-5.50
6	64.00	45.50	18.50
7	40.00	10.00	30.00
8	40.00	10.00	30.00
9	40.00	10.00	30.00
10	48.00	10.00	38.00

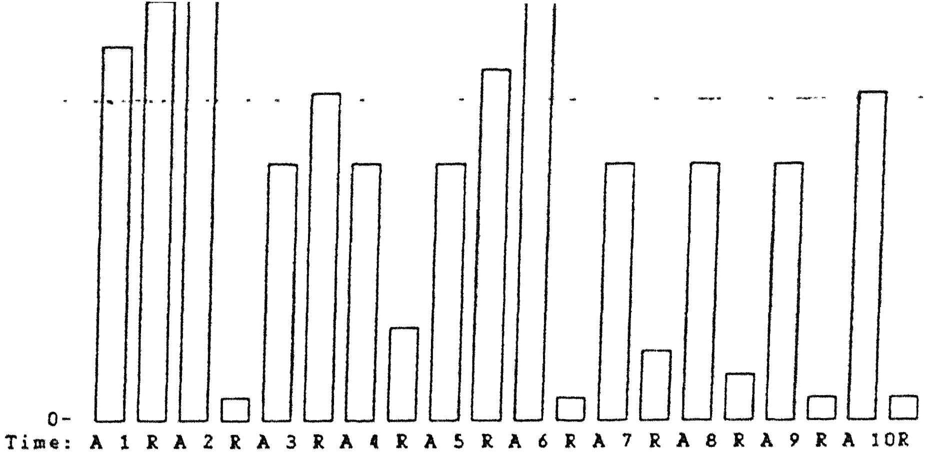
Press S to Stop Browsing otherwise any other KEY to Get Next Record

Work Centre : W4

CAPACITY PLAN

Bucket	Available Machine hours	Required Machine hours	Difference Machine hours
1	112.00	113.17	-1.17
2	128.00	13.00	115.00
3	80.00	91.67	-11.67
4	80.00	33.17	46.83
5	80.00	97.67	-17.67
6	128.00	13.00	115.00
7	80.00	28.33	51.67
8	80.00	18.33	61.67
9	80.00	13.00	67.00
10	96.00	13.00	83.00

Press S to Stop Browsing otherwise any other KEY to Get Next Record



Work Centre :W4   Press any key to continue....

MRP-GT PROCESSING MENU

1: Bill of Material Module
2: Expert GT Module
3: Resource Requirement Planning Module
4: Rough Cut Capacity Planning Module
5: MRP Processing Module
6: Capacity Requirement Planning Module
7: Group Scheduling Module
8: Go To Previous Menu

Input Choice :7

This module can be run with the data entered along with the other modules or it can be run as stand alone module by entering the required data. However, Pl. note that Schedules obtained by running as a seperate stand alone module are not for the integrated data.

:G1   odule ? (Y/N) :n

Group sequence no.: 1

Sequenced Job 1 : BCES
Sequenced Job 2 : BCDS
Sequenced Job 3 : CDGS
Sequenced Job 4 : BCGS
Sequenced Job 5 : BCFS
Sequenced Job 6 : ABDE
Sequenced Job 7 : ABCE

Group Tardiness : 2631.83

Press any Key to Continue ...

This module can be run with the data entered along with the ot
modules or it can be run as stand alone module by entering
required data. However, Pl. note that Schedules obtained by ru
as a seperate stand alone module are not for the integrated da

Would You Wish to Run as a Stand Alone Module ? (Y/N) :y

You Chose to Run as Stand Alone Module ...

Make Sure You have entered the input data in

the files as per the format.Press any Key to Continue .....

```
Group  1       Sequence no.   3

      job sequence number   4
      job sequence number   3
      job sequence number   1
      job sequence number   2
Group  2       Sequence no.   2

      job sequence number   2
      job sequence number   1
Group  3       Sequence no.   1

      job sequence number   2
      job sequence number   1
      job sequence number   3
Total tardiness :11.00
```